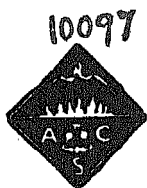IMPERIAL AGRICULTURAL
RESEARCH INSTITUTE, NEW DELHI.

BEARING METALS AND BEARINGS

BY

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GENERAL INTRODUCTION

American Chemical Society Series of Scientific and Technologic Monographs

By arrangement with the Interallied Conference of Pure and Applied Chemistry, which met in London and Brussels in July 1919, the American Chemical Society was to undertake the production and publication of Scientific and Technologic Monographs on chemical subjects. At the same time it was agreed that the National Research Council, in coöperation with the American Chemical Society and the American Physical Society, should undertake the production and publication of Critical Tables of Chemical and Physical Constants. The American Chemical Society and the National Research Council mutually agreed to care for these two fields of chemical development. The American Chemical Society named as Trustees, to make the necessary arrangements for the publication of the monographs, Charles L. Parsons, Secretary of the American Chemical Society, Washington, D. C.; John E. Teeple, Treasurer of the American Chemical Society, New York City; and Professor Gellert Alleman of Swarthmore College. The Trustees have arranged for the publication of the American Chemical Society series of (a) Scientific and (b) Technologic Monographs by the Chemical Catalog Company of New York City.

The Council, acting through the Committee on National Policy of the American Chemical Society, appointed the editors, named at the close of this introduction, to have charge of securing authors, and of considering critically the manuscripts prepared. The editors of each series will endeavor to select topics which are of current interest and authors who are recognized as authorities in their respective fields. The list of monographs thus far secured appears in the publisher's own announcement elsewhere in this volume.

The development of knowledge in all branches of science, and especially in chemistry, has been so rapid during the last fifty years and the fields covered by this development have been so varied that it is difficult for any individual to keep in touch with the progress in branches of science outside his own specialty. In spite of the facilities for the examination of the literature given by Chemical Abstracts and such compendia as Beilstein's Handbuch der Organischen Chemie, Richter's Lexikon, Ostwald's Lehrbuch der Allgemeinen Chemie, Abegg's and Gmelin-Kraut's Handbuch der Anorganischen Chemie and the English and French Dictionaries of Chemistry, it often takes a great deal of time to coördinate the knowledge available upon a single topic. Consequently when men who have spent years in the study of important subjects are willing to coördinate their knowledge and present it in concise, readable form, they perform a service of the highest value to their fellow chemists.

It was with a clear recognition of the usefulness of reviews of this character that a Committee of the American Chemical Society recommended the publication of the two series of monographs under the auspices of the Society.

Two rather distinct purposes are to be served by these monographs. The first purpose, whose fulfilment will probably render to chemists in general the most important service, is to present the knowledge available upon the chosen topic in a readable form, intelligible to those whose activities may be along a wholly different line. Many chemists fail to realize how closely their investigations may be connected with other work which on the surface appears far afield from their own. These monographs will enable such men to form closer contact with the work of chemists in other lines of research. The second purpose is to promote research in the branch of science covered by the monograph, by furnishing a well digested survey of the progress already made in that field and by pointing out directions in which investigation needs to be extended. To facilitate the attainment of this purpose, it is intended to include extended references to the literature, which will enable anyone interested to follow up the subject in more detail. If the literature is so voluminous that a complete bibliography is impracticable, a critical selection will be made of those papers which are most important.

The publication of these books marks a distinct departure in the policy of the American Chemical Society inasmuch as it is a serious attempt to found an American chemical literature without primary regard to commercial considerations. The success of the venture will depend in large part upon the measure of coöperation which can be secured in the preparation of books dealing adequately with topics of general interest; it is earnestly hoped, therefore, that every member of the various organizations in the chemical and allied industries will recognize the importance of the enterprise and take sufficient interest to justify it.

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PREFACE

A survey of the literature on bearing metals and bearings showed that a great many valuable articles had been published in various foreign and domestic periodicals and in the transactions of technical societies. This material was so widely scattered as to be practically useless. At the suggestion of the Committee in Charge of the Monograph Series of the American Chemical Society, I have prepared the volume herewith presented.

The chapters preceding the bibliography were prepared with the idea of aiding persons not familiar with the subject to gain some idea of the fundamental principles involved in the selection of bearings and bearing metals, and to facilitate reference to the abstracts and the bibliography which follow them.

No claim is made as to the validity of any theory or practice that is set forth in any portion of the book, but it is my hope that the authors of the various articles will find their theories and practices correctly interpreted, and that the reader will get a clear picture of the present status of bearings and bearing metals.

Every effort has been made to give full credit to authors of articles and to publishers of both articles and books that are referred to in the introductory chapters as well as in the bibliography. I may owe debts to individual authors of which I am not aware for one inevitably forgets some sources of the accumulated store of information on so broad a subject as that covered in this volume. To my unknown debtors I am very grateful, as well as to those whose names appear in this foreword.

W. M. CORSE,

Washington, D. C.
September 21, 1929.

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PART i

HISTORY

BEARING METALS AND BEARINGS

A bearing is a mechanism devised to provide for rotation or for the sliding of two surfaces in contact with minimum friction.

The first bearings were probably thrust bearings. Long before the invention of the wheel, ornaments or implements of stone, bone, or shell were drilled with holes to receive thongs or cords. The bow-string drill, which the Indian jewelers of the Southwest use today, was invented before the dawn of history. The upper end of this drill, apparently first held in the teeth, was later kept in place, and greater pressure applied, by the use of a hollowed-out stone or block of wood held in the teeth or the hand. Such was the first thrust bearing. The first radial bearings were, perhaps, those of the ox-cart with its solid wooden wheels.

Wood was a satisfactory bearing material as long as there was no need to move loads rapidly. But when war became the big business of the world, and horse-drawn chariots came into use, metal-lined bearings became necessary. Horse-drawn chariots were used in the Trojan War, 1100 B. C., while the memorials of Rameses II, 1300 B. C., show whole squadrons depicted thereon. Czochralski and Welter are authorities for the statement that iron bearings were used in ancient India and China.

After the period of the Trojan Wars, when horse-drawn chariots were comparatively new toys, definite information as to the status of bearing materials and bearings is lacking, but we find that such machines as were in use during the Middle Ages had crudely constructed wooden bearings.

About the beginning of the fifteenth century we find evidences of renewed development in engineering fields. The first drawings and detailed descriptions of bearings date from the sixteenth century; Czochralski and Welter give reproductions of some of these old drawings. One shows the shaft of a water wheel resting on a wooden block, held in place by an iron strap bent to fit the shaft; another shows the forerunner of the present overhead lineshaft bearing in which the

shaft rotates in a hole through a wooden block which is reinforced by an iron strap; a third figure shows a crude form of roller bearing. This, however, seems to have found little application. The authors state that the last two figures appeared in a work published in 1588.

The development of the turning lathe in the eighteenth century was favorable to progress in bearing construction. The conical pivot bearing was introduced during this period, and two piece adjustable bearings were perfected also. A lathe bearing of this kind is illustrated in a work published in 1756.

Very diverse opinions were held as to the suitability of different bearing materials. Wooden bearings were lined sometimes with iron, sometimes with brass or bronze, and often with leather or fabric.

DEFINITION OF BEARING METALS.

For the purposes of this volume the term "bearing metal" will be used to designate the metal that forms the bearing surfaces of sliding contact bearings.

A good bearing metal must be able to carry the weight of the shaft and stand up under steady or suddenly applied loads, or even blows in some types of service, without flowing out or cracking. A certain amount of plasticity is desired in bearing metals to compensate for minute irregularities in the shaft or bearing surface. This plasticity permits yielding, thus avoiding dangerous stresses in the bearing and the shaft, and preventing overheating and rapid wear of these parts. The more accurately the surfaces of bearings and journals are machined, aligned, and kept in alignment, the less plasticity is required in the bearing metal. It is desirable, of course, that a bearing metal should have a low coefficient of friction. Under most operating conditions, the friction depends on the properties of the lubricant, the unit pressure on the bearing, the speed and the temperature.

A good bearing metal must have a low rate of wear to reduce the need for frequent replacements and adjustment of the bearings. It must wear more rapidly, however, than the journal or shaft running on it, because replacement of the journal or shaft is more difficult and costly than replacement of the bearing.

In many cases a bearing metal of good running properties is not strong enough to support the load by itself, but it is used as a comparatively thin lining in a shell of some strong and cheap material such as cast iron, or, if this is not desirable, steel or bronze. On the other hand,

a strong and hard material is sometimes desired for a bearing metal, particularly where accuracy is required. In such cases both the shaft and the bearing metal must be carefully machined and finished by scraping, grinding or lapping.

HISTORY OF DEVELOPMENT OF BEARING METALS.

Special alloys for bearing purposes were first introduced between 1792 and 1817, and the rapid progress of mechanical engineering since that time has been greatly aided by the development of better bearing metals, improved bearing design, better lubricants and methods of lubrication.

Alloys produced in the eighteenth century and the early part of the nineteenth century were suitable for bearing purposes from the point of view of running quality, but they were not strong enough to support heavily loaded shafts without squeezing out. A wider use of these alloys became possible, however, when, in 1839, a United States patent was issued to Isaac Babbitt covering the use of a soft metal lining in a harder and stronger shell. Babbitt used a comparatively soft tin-base white metal, but did not restrict the claims of his patent to any particular composition. The advantage of using a soft metal lining in a harder shell is that the load carrying capacity may be increased without sacrificing the plasticity which permits the bearing surface to adjust itself to the contour of the shaft, or to a slight lack of alignment. This plasticity was lacking in the tin bronzes used in the early days of railroading, and hot boxes were common because of faulty adjustment.

In 1870, Hopkins lined bronze bearings with thin sheet lead, but he found this too plastic. Antimonial lead, which is harder, proved to be more satisfactory. This "antifriction alloy" was the antimonial lead derived from the residue of the silver refineries. A little later compositions containing additions of tin and copper were found to be superior to the antimonial lead.

The need for a more plastic metal than bronze or cast iron suggested the idea of lining bearings with soft metal. But for a long time after the introduction of these lining metals little progress was made toward improving the plasticity of bronze or other hard alloys, so that satisfactory bearings could be made entirely of the same kind of metal. Developments here and in England have been directed toward the production of a bronze containing considerable amounts of lead to increase its plasticity.

The making and founding of such alloys proved difficult, and much investigation was necessary before satisfactory methods were obtained. About 1870, Alexander Dick in England invented the alloy Cu, 80; Pb, 10; Sn, 10. This was the standard railroad bearing metal in that country for many years. In 1892, Dr. C. B. Dudley, chief chemist for the Pennsylvania railroad, published the results of a long series of tests on actual bearings in service, which showed that the rate of wear and the tendency to overheat diminished with the increase of the lead content, and increased as the tin content increased. He produced Ex. B metal, composition Cu, 77; Pb, 15; Sn, 8, but could not obtain alloys having a higher lead content in a state of uniform distribution. This Ex. B metal became the standard bearing metal on the Pennsylvania Railroad, replacing their Standard S, which was the same as Dick's Bronze.

In 1900, a patent was granted to G. H. Clamer and J. G. Hendrickson for a series of lead bronzes containing over 20 per cent lead and less than 7 per cent tin. Their invention was based on a scientific knowledge of the properties of copper-tin alloys. Previous investigators, workers in pure science, had determined the melting and the freezing points of the copper-tin alloys, showing that if the tin content was not over 9 per cent one constituent only crystallized out of the molten alloy on freezing, while a second constituent crystallized out before the melt was solid if the tin content was above 9 per cent. Later investigators have shown that a single constituent or solid solution may be maintained with a tin content up to 16 per cent, but only when carefully regulated conditions are maintained. For practical purposes the transition point is about the 9 per cent tin content.

Considerable heat was evolved when this second constituent crystallized and the process required a comparatively long time, increasing with the amount of tin up to a tin content of 21 per cent. Due to this secondary crystallization, the time of freezing alloys containing over 9 per cent tin was longer than those containing less, in spite of the lower temperature interval over which freezing took place.

Clamer and Hendrickson's invention consisted in limiting the ratio of tin to copper, to 9 to 91, so that freezing took place quickly and trapped the lead before it had a chance to sink through a partially solid metal which could not be stirred.

Other ways were found to make high-lead bronzes, notably the method of A. Allan. The patent controversy between Allan and Clamer is given in the abstracts.

Allan's method involves the use of sulfur which diminishes the temperature range in which molten lead and copper are immiscible, so that segregation difficulties are less aggravated by segregation in the liquid state. In all probability the knowledge of the effect of sulfur was arrived at accidentally, and not through the results of scientific investigation as in the case of Clamer's alloys.

The lead bronzes now find wide applications on the railroads and in stationary machinery where they stand up under severe conditions. Specifications for six standard lead-bronzes were drawn up by the American Society for Testing Materials in 1921. These alloys are being used in the automotive industry.

Types of Bearing Metals.

Three types of bearing metals have been selected for discussion in these chapters. The White Metals, the Bronzes, and the Graphite Bearing Metals.

White Metals.

The term "white metal" refers, in this volume, to the white base-metal alloys of low melting point. This term originated before aluminum alloys became common, and is not applied to them. The term, therefore, shall be understood to refer to the tin-base, the lead-base, and the comparatively new alloys of lead with alkali and alkaline earth metals.

The general requirements of a white metal for bearing purposes were stated in a lecture by R. T. Rolfe before the North East Coast Section of the British Institute of Metals in 1926, as follows:

"It should give good adhesion to the shell (if not a film of oil of low conductivity will be formed between shell and bearing, leading to overheating). It should have high compressive strength at working temperatures, good wearing qualities, low coefficient of friction, and finally sufficient plasticity to compensate for any inequalities of alignment."

The ordinary white bearing metals are essentially alloys of lead, tin, antimony, and copper. Either lead or tin is usually the major constituent. The high tin alloys are superior mechanically but are more expensive. Tin and lead harden each other somewhat, but straight lead-tin alloys are not suitable for bearing metals. The addition of antimony causes a large increase in the hardness of both of these metals and their alloys.

Not all of the alloys of this system are suitable for use as bearing metals. Those containing over 25 per cent antimony are too hard and brittle, and those containing less than 5 per cent antimony are too soft and yielding. A measure of the plasticity—that is the ability of the bearing metal to adjust itself to the contour or alignment of the journal—is shown by the amount which a specimen of the alloy may be compressed before cracking.

The tables in the back of this volume give the composition and properties of white bearing metals, particularly those of the American Society for Testing Materials, and of German Industrial Standards (D. I. N.) standard alloys.

The applications of some of these alloys are also given. Many of them contain copper, in addition to lead, tin and antimony. The copper is added primarily to prevent segregation, though it also improves the mechanical properties somewhat by stiffening the ground-mass. If no copper is present, the first constituent to crystallize out of the molten alloy on cooling is the compound SbSn, which forms cubical crystals lighter than the liquid from which they segregate. These crystals consequently rise and segregate, unless special precautions are taken. If more than 1 or 2 per cent of copper is present, the first constituent to crystallize is a copper-rich one, containing Cu and Sn in the tin-base alloys, and the compound Cu_2Sb in the lead-base ones. Both of these constituents crystallize as needles and form an interlocking network which entraps the subsequently formed cubes of the SnSb compound and prevents them from rising.

Alloys containing less than 10 per cent tin should contain very little copper. The specifications of the American Society for Testing Materials limit the amount of copper in such alloys to 0.5 per cent, while in the German Industrial Standards (D. I. N.) alloys the copper content of those containing 10 per cent tin or less is set between 1 and 2 per cent. Experiments at the Chicago Bearing Metal Company showed that "the addition of only a few tenths of a per cent of copper to such an alloy as Pb, 82-84; Sb, 9-11; Sn, 6-8 will cause it to froth on pouring at any temperature below 482° C. Most of the copper may be removed from such an alloy by sweating." These alloys, according to Bauer, have very little tendency to segregate anyway, therefore the copper is not necessary for its prevention.

There is some difference of opinion as to the proper pouring temperature. It will vary somewhat with the wall thickness of the casting to be made, and the temperature of the mold. The general rule for

pouring these alloys is to pour at the lowest temperature at which the metal will completely fill the mold. Mr. E. R. Darby has shown that the lead-base alloys maintain their fluidity almost down to their melting points, while the tin-base alloys lose fluidity some 100°-150° C. above their melting points. Darby's fluidity measurements showed that the pouring temperatures given by the American Society for Testing Materials for the standard white-metal bearing alloys, while lying near the points of maximum fluidity in some cases were considerably too low in other cases. This was especially true of Alloy No. 5, composition Sn, 65; Pb, 18; Sb, 15; Cu, 2; for which Darby found the lowest permissible pouring temperature to be 500° C., instead of the specified temperature of 366° C. Pouring temperatures of the American Society for Testing Materials lead-base white metals lie between 325° and 375° C., while pouring temperatures of the tin-base metals lie between 440° and 500° C. Czochralski and Welter give 400° C. as the pouring temperature both of Sn, 80; Sb, 15; Cu, 5; and Pb, 80; Sb, 15; Sn, 5.

The advantages and disadvantages of the lead-base and tin-base white metals may be stated briefly as follows: The tin-base alloys are superior mechanically, those containing about 80 per cent tin possessing maximum strength and hardness (compressive strength about 20,000 pounds per square inch; Brinell hardness about 28). The lead-base alloys are much softer and less strong (compressive strength 13,000-15,000 pounds per square inch, Brinell hardness 15-20). Since the high price of tin increases the cost of the tin-base alloys, for many purposes, advantage is not taken of their better properties as it is more economical to use a lead-base alloy if the design permits. However, where economy of space and weight are essential, as in aircraft engines, the tin-base alloys will continue to be used, as the same load capacity can be obtained with smaller bearings. Another disadvantage, as mentioned above, is their low fluidity near the melting point which makes it necessary to pour them at temperatures of about 100°-150° C. (180°-270° F.) higher, at least for thin linings, in spite of the fact that they melt at about the same temperatures as the lead-base alloys.

White metals made wholly or partly from scrap metal often contain impurities, the most harmful of which are zinc and aluminum; the amount of these impurities is limited to zero in the American Society for Testing Materials specifications for white metals. Other impurities are iron, arsenic, and phosphorus. The purification of bear-

ing metals and reclamation from scrap is well described in papers by
E. R. Thews.

In view of the high price of tin, and the difficulty of obtaining it
at times, a condition that faced the United States during the War,
much work has been done to discover alloying ingredients to improve
the properties of the lead-base alloys.

These new alloys consist of lead hardened by the addition of small
amounts of alkali and alkaline earth metals. In this connection it was
discovered that a small amount of sodium gave the same hardness
as a much larger amount of antimony. Literature references show that
an alloy containing 0.5-4 per cent sodium "Noheet" was patented in
1905. It had satisfactory properties as a bearing metal, but it was
subject to atmospheric corrosion.

In 1915, in the United States, Frary and Temple invented a series
of alloys of lead hardened with small amounts of the alkaline earth
metals. Some of these such as "Ulco Metal" or "Frary Metal" were
found suitable for bearing linings. Similar alloys known as Mathesius
metal and Lurgi Lagermetall were developed in Germany about the
same time by Walter and Hans Mathesius; these have been covered
by patents in the United States. Lurgi was the standard lining metal
on the German railroads for some time, but it has been succeeded by
Bahnmetall whose resistance to atmospheric corrosion is greater owing
to the addition of 0.05 per cent lithium. This alloy is covered by the
patents of G. Welter, assigned to Metallbank and Metallurgische
Gesellschaft, which company also holds the patents for the Mathesius
and Lurgi metals.

Two lines have been followed in the attempt to improve the prop-
erties of the lead-base alloys, namely,

1. Improving the strength of the soft lead-rich matrix by adding
a substance which forms a solid solution with it, and

2. Increasing the strength of the other constituents embedded in
the lead-rich matrix, or even finding new and better hard constituents.

The first method is exemplified by Thermit bearing metal, in which
the matrix of a bearing metal containing 72-78 per cent lead is
strengthened by the addition of 0.7-1.5 per cent nickel and 0.7-1.5 per
cent cadmium. The compressive strength of this alloy is 25,600 pounds
per square inch, and the Brinell hardness 29, so that it is somewhat
superior mechanically even to the high-tin alloys.

The second method is exemplified by the lead-alkali and lead-
alkaline-earth-metal alloys. Here new hard constituents are formed

which are intermetallic compounds of lead with the added metals. The best example of this type is probably Bahnmetall which, as mentioned above, is a standard lining metal today on the German National Railroads. It has a compressive strength of 25,000 to 30,000 pounds per square inch, and a Brinell hardness of 34. The hardness, which is high for a lead alloy containing such small proportions of alloying ingredients, is accompanied by a good degree of plasticity. The metal may be compressed 28 per cent without cracking (cylindrical specimens). Bahnmetall contains 0.73 calcium, 0.04 per cent lithium, and 0.58 per cent sodium; the balance is lead.

Satisfactory bearing metals can be produced from lead-alkaline-earth-metal alloys without using tin, and the small amounts of alloying ingredients required add little to the cost. However, these alloys require special methods of manufacture and suffer loss of their alloying constituents on remelting which is a disadvantage. The pouring temperature of these alloys is high, 500° C-600° C, and most of them are more or less susceptible to atmospheric corrosion, although this fault is said to have been eliminated in Bahnmetall by the addition of the small amount of lithium mentioned. While linings can be cast of these metals in bearing metal foundries properly equipped, making them up from their components is a special problem. This is usually accomplished by electrolysis of a mixture of fused alkali and alkaline earth salts, using a molten lead cathode.

When the hardened lead is once installed as a bearing it usually gives excellent service. There is some difficulty in handling the alloy, however. Some of its properties resemble those of lead; namely, in the tendency of lead to give comparatively high shrinkage in changing from the liquid to the solid state, and in the comparatively poor adhering properties of lead for copper and iron. In shop practice there is some difficulty experienced in the use of these alloys. The lead-barium-calcium alloys are very subject to oxidation by drossing, tending to lose some of the hardening elements; namely, barium and calcium. However, this tendency of excessive drossing has been largely overcome by the addition of very small amounts of other elements.

BRONZES.

Under some conditions soft metal linings are not always suitable and bearings are made entirely from some kind of bronze, or, in some cases, of cast iron, wood, or other materials. Even where bronze is used on top of cast iron, as in a die-cast liner or bushing, it is not

spoken of as a lining metal. Most bronzes used today for bearing metals contain considerable amounts of lead to give them that degree of plasticity which will compensate for a slight want of fit or alignment of the bearing. Lead-containing bronzes are also used for supporting white-metal linings when a somewhat plastic backing metal is desired. For instance, red brass containing lead is used as the standard backing metal for Bahnmetall or other white metal on the German National Railroads. Where accurate fit and alignment can be maintained, it is permissible to use lead-free bronzes, usually phosphor bronzes. These are strong, very hard, and have a low coefficient of friction. They will wear rapidly, however, and will overheat and score the shaft if poorly fitted or if the supply of lubricant fails.

The properties of bronze bearing metals are given in Tables 2-4 at the end of this volume, also the specific applications of these in railroad service.

The ordinary bronzes consist of a copper-rich solid solution with tin, in which is suspended the so-called "delta" constituent—a hard compound of 21 per cent tin. If more phosphorus is present than needed to deoxidize the metal, the compound Cu_3P may be present. Both this compound and the delta constituent are harder than soft steel, therefore care must be taken not to use too soft steel journals against bronze. Also, if the metal has been burnt in founding, crystals of tin oxide—one of the hardest substances met with in alloys—will be present, and these always score the journal.

The lead-bronzes contain lead held mechanically in a matrix of tin-bronze, very little of the lead being in solid solution. Some recent work at the Bureau of Standards indicates that the following results are applicable to bronzes with tin and lead:

"1. Alloys containing less than 4 per cent tin and 4 per cent lead have very high wear rates. An increase in either tin or lead over this amount decreases the wear rate. The rate of this decrease is slow with increases in tin or lead over 7 per cent.

"2. Alloys with high tin and low lead have high friction. As lead is increased or tin decreased or both, the friction becomes progressively less.

"3. Alloys with less than 4 per cent lead develop rough wearing surfaces in unlubricated wear. Alloys high in tin develop rougher surfaces than those low in tin. An increase in lead or decrease in tin results in progressively smoother surfaces.

"4. Resistance to pounding is governed by the ratio of tin to copper.

The higher the ratio of tin to copper the better the resistance to pounding. Increase in resistance to pounding may be obtained by increasing lead as when copper is reduced the ratio of tin to copper increases.

"5. Increase in either tin or lead decreases the toughness. The effect of lead is a gradual decrease while the effect of tin is gradual up to about eight per cent. When the tin is increased over eight per cent the alloys become very brittle.

"6. Hardness—The hardness of the alloys is largely effected by tin content and very slightly by lead content. Hardness is not a measure of resistance to pounding."

The lead-bronzes, like all mechanical mixtures of two metals having different specific gravities and different melting points, are liable to segregation. This is further aggravated by the fact that copper and lead are immiscible in the liquid state unless the temperature is considerably above the melting point. The addition of sulfur diminishes the range of immiscibility and thus aids in the prevention of liquation. Clamer's method of preventing segregation by limiting the ratio of tin to copper is described above. R. E. Lee and F. B. Trace investigated the phenomena of segregation in the high-lead bronzes and the results they obtained are given in the abstracts.

GRAPHITE BEARING METALS.

The graphite bearing metals are, in fact, bronzes or white metals mixed with graphite, the latter being a material possessing negligible strength and usually classed as a lubricant. The graphite in an alloy is held mechanically in a state of fine dispersion. Its function is to absorb the lubricant in relatively large quantities. Therefore, graphite-bronze bearings frequently do not need lubrication for a long time. This is a decided advantage in enclosed machinery, such as motors.

The graphite may be incorporated in the molten alloy under pressure, as in the case of Graphalloy, or by sintering the partially reduced oxides of the metallic constituents with graphite under high pressure as in Genelite. A similar alloy is Durex.

Most of the graphite alloys are porous, serving to hold the lubricant as noted above, or, in some cases, so porous that the lubricant may be supplied through the bearing metal itself by capillarity. Porosity, however, is accompanied by mechanical weakness, so that the alloys serve only as small bushings or linings.*

* Porosity may also be secured by using other porous materials than graphite, such as small stones.

Types of Bearings.

There are two basic types of bearings, namely sliding contact bearings and roller contact bearings. Each type is divided according to the manner in which it takes the load into (a) radial bearings, where the bearing opposes forces applied perpendicular to the axis of the cylindrical shaft; (b) thrust bearings which take loads parallel to the axis of the shaft, *i.e.* end thrusts; and (c) angular contact bearings which take both kinds of loads.

Sliding contact bearings may be either plain bearings, in which the bearing surface is continuous except for oil grooves, or pivoted-block bearings such as the Kingsbury and Michell, which are used almost exclusively today for taking large end-thrusts. In the case of sliding contact bearings, bending stresses in the shaft must be taken care of by plasticity of the bearing metal, or by making the whole bearing self aligning.

Roller contact bearings may be either ball or roller bearings, the latter using either cylindrical or tapered rollers. Ball bearings are now made which allow quite a large departure from alignment.

Factors Deciding Choice of Type.

The first cost of rolling contact bearings is for the most part greater than that of the sliding-contact bearings to which they are equivalent, as they are usually made of high grade alloy steels. The operations of forming, machining, and heat treating these are expensive.

The pivoted block types of sliding contact bearings are naturally more expensive than plain ones of the same size, but they can carry a load many times as great and carry it more reliably.

Sliding contact bearings are made of a great variety of materials with corresponding variations in cost. In white-metal bearings, the cost is determined largely by the amount of tin in the composition.

The prospective user will do well to consider carefully the use to which bearings will be subjected before making a selection.

Bearing Design.

As the object of a bearing is to eliminate as far as possible friction between two moving surfaces in contact with each other, bearing design is of major importance to the engineer. When designing bearings one must consider the materials in the bearing itself, the material of the

shaft, in the case of journal bearings, and finally the lubricant which tends to reduce the friction. Reduction to a minimum of the following economic losses depends on the proper design of bearings, and on the choice of materials and lubricants:

1. *Loss of Power.* The greater the bearing friction, the greater the amount of energy converted into heat, which raises the temperature of the machine, or part, disastrously if not carried away faster than it is developed.

2. *Wear.* The operation of the machinery is accompanied by wear of the bearing surfaces in two ways:

(a) Uniform wear which can be compensated for by adjusting the bearing from time to time, or

(b) Scoring, which necessitates machining of worn parts, and in many instances replacement of the damaged part. Seizing, which may be described as an aggravated case of scoring, is a welding together of the metal surfaces, which of course necessitates replacement.

Wear involves not only the loss of the metal itself, but the cost of the labor employed in constructing the bearing, because it becomes worthless and must be discarded or repaired before a large portion of it is worn away. Excessive wear results in a general depreciation in the value of the machine, because loose bearings, if not taken up, lead to excessive vibration or pounding. The loosened bearings may fracture themselves or other parts of the machine. Rapid wear results in high maintenance costs.

3. *Consumption of Lubricant.* Even when circulation is provided for the lubricant, there is waste either by leakage or evaporation, or by chemical and physical changes which take place in the lubricant, thus gradually unfitting it for further use.

The first step in designing a bearing is to determine what overall dimensions are required to support the load under the conditions of operation of the machine. The projected area of the bearing must be great enough to:

(a) Prevent the bearing metal from flowing out under the load, and

(b) Maintain fluid lubrication under operating conditions.

The first requisite depends on the mechanical strength of the bearing metal, its frictional and wearing qualities, as well as on the accuracy of alignment and fit which it is possible to obtain in constructing the machine, while the maintenance of fluid lubrication depends on the distribution of the lubricant in the bearing and the

correct design of the oil grooves. Such design should be based on a knowledge of the distribution of pressure within the bearing.

Incorrectly designed grooves are much worse than none at all, and may prevent the establishment of fluid lubrication under any conditions. The points of entrance of the oil should be so located that oil is drawn into the bearing by the rotating shaft; that is, from regions of low to those of high pressure. Sharp-edged grooves are to be avoided as they tend to break the oil film. Grooves should not extend to the ends of the bearing, as they would not allow pressure to be built up in the oil film.

No detailed directions for the design of oil grooves can be given here, and the reader should study the practice of reliable machine builders. The practice of the Westinghouse Machine Co. is given by figures and a table in Marks Mechanical Engineers' Handbook.

BEARING TROUBLES AND FAILURES.

Bearing troubles and failures may be traced to one or more of the following causes: faulty design of bearing, materials unsuited for the service, improper lubrication, and incorrect methods of manufacture.

Faulty Design. The design of bearings is interconnected with the design of the machine as a whole. Thus if flexure of a shaft occurs, either the shaft must be made stiffer, or the bearing made self-aligning. If flexural stresses occur in a shaft that is not stiff enough, and the bearings are not self-aligning, fracture of the bearing lining or of the shaft itself may take place, if the bearing is too heavy and rigid. On the other hand, if lighter bearings are used, excessive flexure may occur, resulting in destruction of the bearing or damage to other parts of the machine. For instance, flexure of a shaft carrying gears may lead to uneven wear and breakage of the teeth. Rapidly alternating stresses may cause the loosening of linings in bearings which are not rigid enough, even when the maximum value of the stress is below the yield point of the material. The choice of the dimensions of the shaft or journal is just as important as that of the bearing, and the two must be considered together, because if the shaft is too small for the load no bearing will give good service. The effect of fatigue is especially to be guarded against in designing bearings, on which the load varies in amount or direction.

Overheating of a bearing may be caused by too small clearance resulting in friction, or imperfect distribution of the lubricant. On the

other hand, there may be too great a clearance with consequent failure
to maintain fluid lubrication. While satisfactory dimensions and clear-
ances for bearings can be found in standard engineering handbooks,
so that bearings as built generally give satisfactory service unless of
unusual design, the clearance may be allowed to wear too great in
service, or it may be too small when the bearing is refitted, with
equally disastrous results.

Bearing design is sometimes faulty as to the point of entrance of
the oil and as to grooving. The pressure in an oil film may be many
times that of any oil supply system, therefore bearings in which the
oil entrance is at a region of high pressure will fail to give good service.
In such bearings, a fluid film cannot be built up, and the bearing then
operates under conditions of partial lubrication. The oil grooves may
be so constructed in bearings that regions of high and low pressure are
connected and the pressure difference otherwise possible cannot be
built up. Grooves with sharp leading edges are undesirable in that they
tend to break the film, especially under conditions of thin film lubrica-
tion. Oil rings sometimes fail to deliver the necessary amount of lubri-
cant and overheating follows.

Unsuitable Materials. The bearing as a whole must be strong
enough to support the load and any bending stresses in the shaft, as
well as to prevent the bearing metal from cracking or flowing out under
the maximum pressure in the bearing, due to the load on the shaft.

Bearing metals may give poor service because of unsatisfactory
wearing qualities. These qualities depend on the properties of the
several constituents, and may be greatly affected by small amounts
of impurities. More actual information on this subject is needed,
however.

Lubrication. Many bearing troubles are caused by the unsuitability
or the deterioration of the lubricant. The lubricant chosen should be
one which will give good service under conditions of partial as well
as perfect fluid lubrication. New oils should be watched carefully in
service, and changed when signs of faulty lubrication appear. Oxida-
tion is one of the chief causes of deterioration of oils, though there is
evidence indicating that some oxidation is necessary. In automobile
engines, oil may become diluted with gasoline, or contaminated with
carbon. In turbines, emulsification of the oil with water is the greatest
danger.

Incorrect Methods of Manufacture. Many bearing troubles are due
to the metal being improperly cast or treated improperly after it has

been cast. White metals cast at too high temperatures, and too slowly cooled, have a coarse-grained structure and are unsuitable for bearing metals. On the other hand, if they are too rapidly cooled and quenched as soon as solid, they will be too fine grained for bearing metals. Lead-bronzes, however, must be cast at rather high temperatures to prevent segregation.

When bearings are lined with white metal it is desirable that the backs should be heated to avoid shrinkage strains due to unequal contraction of the two metals after the lining becomes solid, because such internal stresses may cause the lining to crack in service. Once the lining is loosened from the back, oil creeps through the apertures. As oil is a poor conductor of heat the temperature in the bearing may rise to a dangerous point. If the lining cracks, the pressure of the oil may be instrumental in loosening it, if the oil connects with spaces between the lining and the back.

Oxidation of bearing metals in the molten state is always to be avoided, as some of the products of oxidation are particularly deleterious. The worst of these is tin oxide, which may occur as diamond shaped crystals in both bronzes and white metals. It is extremely hard and will score a hardened steel journal.

TESTING BEARING METALS AND BEARINGS.

Static Tests. The static mechanical tests that are of importance in testing bearing metals are (1) the compression test, (2) the hardness test, and (3) the transverse bending test. The tensile test is of slight importance, as bearing metals are rarely under tension in service but may be useful for comparison.

Compression Test. In compression tests the size and form of the specimen are of importance. As many non-ferrous metals have no well defined elastic limit and yield point, nor do they always fail by shearing off or cracking, it is necessary to give arbitrary definitions of elastic limit, yield point and ultimate compressive strength. It will be best to use the definitions given by the American Society for Testing Materials in the results of their tests on white metals, and also to use specimens of the same dimensions. The per cent compression under some definite load, or at the beginning of cracking is also sometimes of value.

Hardness Tests. Practically the only hardness test of value for bearing metals is the Brinell or some modification thereof. The mixture

of hard and soft crystals of which some bearing metals are composed is too coarse-grained for the scleroscope to give good results. Some work has been done on instruments designed to measure the hardness of the individual constituents, such as the Bierbaum microcharacter. Such instruments require a carefully shaped edge or point to give consistent results. With the microcharacter, results were variable, and those obtained by different observers showed rather marked variations. Some such scratch test, however, would be desirable to find out if the alloy contained any constituents that were harder than the steel of the journal. The hardness measured by the Brinell instrument tells nothing about the scratching quality of the different constituents, but, rather, its resistance to deformation. The Brinell test will probably take the place of the compression test in routine testing of bearing alloys, as it is much easier and quicker to carry out.

Transverse Bending Tests. The transverse bending test is of importance in bearings which may be eccentrically loaded. This is the only case in which part of the bearing metal is under tension. Where such tests have been conducted in this country they have usually been made on the complete bearing to see how it stands up as a whole. In some parts of Germany, however, it has been the practice to make transverse bending tests on bars of the bearing metal itself.

Dynamic Tests. In dynamic tests the material is subjected to varying loads or to impact. While bearing metals are actually subjected to such loads in service, particularly in automotive and railroad service, little has been done to develop methods of testing under these conditions. The results obtained with dynamic tests depend greatly on the machine and type of specimen used and results of experiments by different methods are not often comparable. The greater part of this work to date has been on steels.

Fatigue Tests. The resistance to rapidly alternating stresses, that is the fatigue resistance, is a property which has been almost entirely neglected in bearing metals. One fatigue test of importance is the fatigue bending test applied to the complete bearing. This is of importance in automotive engine bearings, particularly aircraft engines, in which the linings sometimes fail because of repeated flexing of a back which is not rigid enough.

In fatigue tests, the stresses are usually below the yield point, and the endurance limit is of the order of magnitude of the elastic limit. To give an idea of the resistance of a metal under such conditions, impact fatigue tests are valuable. The specimens are subjected to the

impact of a definite weight falling always through the same height.
The impact fatigue number is the number of blows required to fracture
or to deform a fixed amount. This information is of importance in
railroad service, where flat wheels and consequent pounding are likely
to occur. Under such conditions, it is desirable that the bearing shall
last until the car can reach a shop. A metal which cracks up or pounds
out after a few blows is worthless. The type of specimen and kinetic
energy of the blow are entirely arbitrary and each user must choose
them to suit his product. This test, however, will be of value in detect-
ing poor material in the course of routine testing.

Notch-bar Tests. The notch-bar impact test, in which a notched
specimen is fractured at a single blow, is not so applicable to bearing
metals, as they are not exposed to such conditions in service. Most
of the bearings have oil grooves, however, which produce some "notch
effect." The conditions in bearings would be duplicated perhaps by
repeated impact tests on a notched specimen. The energy of the blows
being much less than that necessary to fracture the specimen at a
single blow.

Wear Tests. Wear tests have not yet been standardized, and such
laboratory wear tests as do exist may not always apply to service con-
ditions. However, the recent work at the Bureau of Standards offers
much encouragement along these lines.

The mechanism of wear will have to be better understood before
standard tests can be established, and "wear" given a standard defini-
tion. It is often defined as "any deterioration of the bearing metal due
to service, including even cracking." In "wear tests" as generally car-
ried out, the "wear" is a combination of actual wearing away of the
metal and distortion. In some tests the bearing metal is rubbed with
a steel disc or journal, no non-metallic abrasive being present, and
the loss in weight is determined. This loss is considered a measure
of wear.

The recent work on testing of bearing metals at the Bureau of
Standards, which has been reported in the proceedings of the American
Society for Testing Materials, and in the Journal of Research of the
Bureau of Standards in 1928 and 1929, covers a period of several years
and indicates the development of a rather satisfactory testing tech-
nique with the object of finding reasons for the wide variations in the
specifications of different railroads and automobile companies, for
bearings for similar conditions of service.

The direct result of this work has been to arouse the interest of

industrial organizations and technical societies in bearings and bearing metals. While the tests used are not perfect, nevertheless, sufficient agreement has been secured to make some valuable comparisons. This is partly due to the fact that the Amsler wear tests employed were made principally on dry specimens which did not heat even when run at high pressures because the test pieces were in the shape of discs having only a line contact. It was possible under the conditions to run a large number of tests in a reasonable time, and they showed sufficient agreement with different operators at different times to demonstrate their value.

The literature does not disclose elsewhere a similarly good result. Therefore, it would seem that a distinct advance had been made in the testing of bearing metals by the workers at the Bureau of Standards. Questions will arise naturally as to the practicability of a dry test, but when it is considered as one of a series of tests, and not as the final word, its value cannot be doubted.

With standardized testing technique it becomes possible to determine with some accuracy the effect of small quantities of other metals in the main alloy, thus pointing the way to proper specifications and commercial standards.

Several bearing testing machines have been designed which simulate the actual conditions in a bearing. These operate by hanging the bearing on a revolving shaft and weighting it down by means of a pendulum on which weights are suspended. As the shaft is revolved the friction or the torque is determined by the angle at which the pendulum swings while the shaft is revolving. In such machines the bearings are always lubricated, and the wear of the bearing metals is determined by the loss in weight. At first glance one might think that reliable results could be obtained from such a machine simulating actual conditions. As a matter of fact, results obtained have been very erratic and unreliable in many instances, due in all probability to the fact that the area of contact was continually changing as the bearing metal wore, and also that the lubricant used was an important factor in the ultimate result. If such a machine is run without lubricant the temperature rise would be very great, but with an Amsler machine which operates with a line contact, pressure several times above that found in practice can be employed easily without any heating of the specimen whatever.

Important results such as those of Dudley on lead-bronzes, have been obtained from the wear of bearing metals in service, the reports

of the frequency of hot-boxes, etc. Owing to varying conditions of
maintenance, however, only rough average values can be obtained
from such records. These are valuable in that they give an idea of the
reliability of the bearing type and bearing metal in actual service.
Information of this character may be obtained from the so-called
accelerated service tests in which bearings are run under extreme con-
ditions of load, speed, or temperature, corresponding to conditions of
overload or improper maintenance.

<div align="center">LUBRICATION.</div>

The mechanism of lubrication has been studied by many author-
ities; one of the clearest expositions found by the author is embodied
in an article by Dr. Paul Cuypers. Because of the importance of this
article, the author has drawn liberally from those portions describing
the fundamental principles of lubrication.

For a long time friction was ascribed to unevenness of the surfaces
which touched. Projections interlocked and thus offered a resistance
to the relative motion of the surfaces. Nevertheless it has been shown
that when these projections have been polished to almost absolute
flatness the friction is still great enough to cause a quick wearing
away of the surfaces. We are, therefore, forced to the assumption that
the unevenness of the surfaces cannot be the only cause of friction,
and we have to investigate the inner molecular differences themselves
for the further cause of friction.

According to the modern scientific conception, friction depends in
all cases on an interaction but not on an interlocking of the roughness
of the surfaces, but above all on an interlocking of the heterogeneous
electro-magnetic fields of force which radiate from the surfaces. But
if this is the nature of friction, it logically follows further that a de-
crease in friction can only be reached by diminishing, in some way or
another, this interlocking of the electro-magnetic fields of force. This
is exactly the task of the lubricant which we bring between the rubbing
surfaces.

There are two types of lubrication: (1) thick-film (complete lubri-
cation), (2) thin-film (incomplete lubrication).

Thick-film Lubrication. With complete or thick-film lubrication
the lubricating film is so thick that the new friction takes place en-
tirely within the lubricant, at a distance from both rubbing surfaces,
outside the reach of the fields of force radiating from the surfaces. We

understand that in this case the kind and intensity of the two fields of force is entirely without significance, because the thickness of the lubricating film does not permit an interlocking of the fields of force.

In order to maintain a thick film of any fluid lubricant it is necessary, in general, for the bearing surfaces to be inclined to one another at a slight angle. This permits the formation of a wedge of the lubricant, which tends to separate the bearing surfaces and thus serves to support the load. If the surfaces are parallel or inclined the wrong way this wedging action is lost and the main body of the lubricant escapes.

The load-carrying action of a wedge-shaped oil film is similar to that of the air directly under the wing of an airplane in flight. In each case a fluid pressure is developed on the under side of the inclined surface purely as a consequence of the relative motion. On the upper surface of the airplane wing, and on certain portions of the lubricated bearing surface, negative pressures are also developed, and it is simply the resultant of all these positive and negative fluid pressures that supports the load.

Besides having the proper inclination of bearing surfaces, a second prerequisite to insure the maintenance of a thick film is obviously that of having an adequate supply of lubricant in immediate contact with the moving surface.

The only property of a fluid lubricant which can appreciably influence its mechanical action in thick film lubrication is its viscosity. We refer to its viscosity at the true temperature of the film, not at the room temperature or at some arbitrary standard temperature. The chemical composition of such a lubricant has no influence on the result except indirectly through changes that may occur in its viscosity.

The nature of the bearing metal can have no direct influence in thick film lubrication provided the oil actually wets the metal.

Thin-film Lubrication. Any machine at the moment of starting or stopping or reversing its direction passes through zero speed and thereby fails to meet one of the requirements for the maintenance of a thick film. Bearing surfaces that are too heavily loaded on small areas cannot support a thick film; gear teeth and cutting tools, for example. Parallel surfaces like the ways of a planer and the rubbing surfaces of a piston and cylinder cannot in general be expected to maintain a thick film, although they may do so momentarily.

During the starting interval such as mentioned above there is a condition during which, if the speed of the shaft is increased, the coeffi-

cient of friction becomes progressively less until a minimum point is reached. Beyond this minimum point any increased speed results in an increased coefficient of friction which is a function of the speed of the shaft.

This transition from a decreasing to an increasing coefficient of friction is the dividing line between two recognized types of lubrication.

During the period of decreasing coefficient of friction thin-film lubrication prevails and the bearing metal and the oiliness of the lubricant play an important part. As the coefficient of friction increases these factors disappear as complete lubrication (known as thick-film lubrication) is obtained.

In heavy machinery the effect of the speed is to center the journal in the bearing, so that it is surrounded with a uniformly thick lubricating film. In fine mechanisms, where the plane in which friction takes place is not far enough removed from the rubbing surfaces to be completely outside the influence of their fields of force, the case of so-called incomplete-film lubrication is the rule.

Thin-film lubrication depends on some unknown factor or group of factors collectively known as the property of *oiliness*.

Oiliness of a lubricant is defined by Herschel as the property which causes two lubricants of like viscosity, at the temperature of the lubricating film, to give different frictions when used under the same conditions. Generally speaking, lubricants of high oiliness adhere to the bearing surface with greater force than lubricants of low oiliness. Recent tests of oiliness have disclosed the fact that a lubricant may not have the same oiliness when tested in conjunction with different bearing metals.

With incomplete-film lubrication, the lubricant will better fulfill its function of decreasing friction the better it is in position to neutralize the fields of force radiating from the solid surfaces, and to eliminate them as a factor causing friction. For this purpose, in the first place, it is necessary to maintain a continuous film of oil, be it ever so thin, to cover the solid surfaces and offer sufficient resistance to the tangential forces tending to destroy the films. Moreover, the molecules of the lubricant can have special properties for reducing friction, which further increase the effect of the mere presence of the oil film. The sum of these phenomena which maintain a lubricant film under the influences of the solid surfaces, and decrease friction without more fluid friction being caused within the lubricant, is what Cuypers

calls the oiliness of the lubricant, *i.e.* "While with complete film lubrication the viscosity is the factor which causes a decrease in friction, the cause of reduction of friction in the case of incomplete film lubrication is not the viscosity, but the oiliness of the lubricant."

It is the incontrovertible service of Woog to have investigated most thoroughly the factors upon which good oiliness depends, and to have devised a system to accomplish this. It would lead much too far in this place to go further into these most interesting investigations of Woog, but according to him the most important factors which determine oiliness are:

1. The mutual keying together of the molecules of the lubricant, by which we understand the resistance they oppose to pulling apart, insofar as it depends on a single molecule's having a hold on its neighboring molecules. For this hold, the size of the molecular volume is of predominant significance. The greater the molecular volume of a lubricant, so much firmer does it hold even the thinnest film together.

2. The form and dimensions of the lubricant molecule: we should not imagine the molecules as symmetrical, spherical shapes, but as more complicated forms showing strong irregularities. An oil film which consists of long molecules which stand close together like the bristles of a brush is much more resistant to the tendency of rotation than is an oil film consisting of molecules more nearly spherical.

3. The presence of specially active centers of energy in certain molecules, which forces them under certain conditions to take on quite different positions: especially effective are such centers of energy when they are located at the end of the molecule. It appears that the durability of the oil film standing in direct contact with the solid surfaces will be so much the greater the firmer the lubricant molecules anchor themselves to the surfaces. And this anchoring will always be especially intensified if the force of attraction due to the metal surfaces themselves is strengthened by a special affinity of the lubricant molecules in which even such active centers of energy orient themselves towards the surfaces.

4. The fourth factor of oiliness of a lubricant is the elastic stiffness of its molecules.

The comparison of experimental with practical results is very interesting. In practice it has always been found and maintained that the lubrication action of the fatty oils of animals and plants, is better than that of mineral oils. For a long time science, which at first regarded the problem of lubrication from the purely physical point of view of

fluid friction, has thought this experience must be controverted, as neither the viscosity, which was at first mentioned, nor the surface tension which was later thought to be of significance in regard to the lubricating efficacy of an oil, gave any conclusive results in favor of the fatty oils. The matter appears differently today. The better lubrication efficacy of the fatty oils, always maintained in practice, does not rest on their viscosity nor on their surface tension (there are enough mineral oils which show the same characteristics in these respects) but in their essentially greater oiliness.

The fatty oils possess to an extreme all of the factors entering into the question of the formation of high oiliness. They have a much greater molecular volume than equally viscous mineral oils, their form is markedly long—three times as long as wide—and they possess in contrast to mineral oils, polar active centers of energy which act to anchor their molecules fast to the rubbing surfaces. On these grounds, an adsorbed film of fatty oil is always more resistant than an adsorbed film of mineral oil of similar viscosity and therefore the effective decrease of friction in so-called half-fluid friction is always greater and more persistent with lubrication by fatty oils than with lubrication by mineral oils.

The Effect of Bearing Metals on Lubricants.

Quite unexplained are the effects of the metal parts on the oil but there is no doubt that such effects exist to a considerable extent. They may be due to the nature of the metal itself, to the manner of its preparation or to the handling of its surface. As regards the metal itself we know at least this much, that certain metals act catalytically to accelerate the decomposition of fatty oils. This is especially true of copper, zinc, nickel and apparently also antimony and the alloys of these metals. Then it is possible that certain methods of finishing metals originally inert as, for example, iron, may lead to the formation of chemical compounds in the metal which will act especially unfavorably on fatty oils. Finally, contamination of the surface from handling, as in hardening, polishing, etc., may result in chemical combinations. For example, neatsfoot oil, whose chemical structure is especially favorable might form a viscous soapy mass which would have a braking instead of a lubricating effect.

It has been shown that the addition to mineral oil of one or two per cent of such fatty compounds as oleic and stearic acids increases

the lubricating properties tremendously. It is therefore important to study the action of the bearing metals on a molecule with a high molecular value, such as stearic acid, so that the efficacy of the fatty acid in the lubricant may not be destroyed.

Largely because of cost, mineral oil is the common lubricant. It has been shown that the action of one or two per cent of such fatty compounds as oleic and stearic acids increases its lubrication power tremendously. Therefore, in order to retain this superior quality it is essential that we study bearing metals to avoid the use of those metals which will react in such a way as to destroy these valuable properties, thereby decreasing the value of the lubricant. The best lubrication is secured by increasing the durability of the fatty oils by the elimination of unsuitable bearing metals and by avoiding any treatment of the metals as outlined above which has been found by experience to attack the sensitive structure of the fatty oil.

All of which would seem to indicate the tremendous importance of the study of bearing metals and their reaction on the lubricant, in order to be able to select those that act more favorably under definite conditions.

The recognition of the nature of so-called incomplete-film lubrication is new, as is the significance of oiliness. The conception of oiliness is new and also the search for the factors upon which it depends. New and interesting is finally the fact that in the phenomena which at first glance appear to be purely physical, like the reduction of friction, chemical action should be of such predominant importance.

The information thus far obtained concerning oiliness offers a very rich field for further chemical investigations. Until now the problem of lubrication has been attacked solely from the side of the lubricant. Since, however, in the case of friction in fine mechanisms, the fields of force of the rubbing surfaces play such a considerable rôle, and these are entirely dependent upon the nature and structure of the surface molecule, we must in the future turn our attention much more than formerly to the material of the rubbing surfaces, and to the affinities between certain groups of molecules in the lubricant and the molecules of the metal surfaces. In this way alloys will probably be discovered which will be better adapted to orienting certain centers of energy of the lubricant molecules than many of the alloys previously used, and thus an adequate molecular lubricating layer will be better insured.

In the second place, exact investigations of the occurrence or non-occurrence of the catalytic action of certain metals on fatty oils might

be, under certain circumstances, of the greatest value for the entire industry of fine mechanics. For example, there is always oil trouble with certain instruments having brass bearings. If the brass were replaced by tin or tinned metal, a much greater durability of the oil might be attained. The greater reliability in service and prolonged life of the apparatus would compensate for the higher cost of the tin or the tinning.

Finally, it would pay to make a general investigation of the influence of the fatty acids on the different metals. The practician is always inclined to understand by the word "acids" something quite dubious and dangerous. As a matter of fact, there is a great difference between saturated and unsaturated fatty acids, between liquid and solid acids, and all acids do not attack all metals to the same degree. Experimental tests as to which acids are of a harmless nature and which are dangerous, on what alloys they act strongly and which they attack less, would be of interest to all who use oil. Such tests would be all the more welcome since in Woog's process the stearic acid is the chief agent for the reduction of friction.

That by and for itself the free acid present in the lubricant is very effective in reducing the friction, has long been known. For example, in England, Wells and Southcombe proposed in 1920, as a result of their studies, to increase the lubricating value of ordinary mineral oils by the addition of a minute amount of fatty acid.

It would appear, therefore, that there are a number of further problems which await scientific investigation and explanation, whose solution would be of greater value for every oil user and oil maker than all practical tests on single instruments and single lubricants.

PART 2

BIBLIOGRAPHY OF BEARING METALS,
SLIDING-CONTACT BEARINGS,
FRICTION, AND LUBRICATION

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Effect of the Different Components

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SECTION C

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993		BREWER, A. F., The Relation of Clean Air to Efficient Lubrication. *Ind. Management*, 71:284-289.		
994	1927	MCKEE, S. A., Effect of Abrasive in Lubricant. *J. Soc. Automotive Eng.*, 20:3-6.		
994a		BORODULIN, M. W., Resins in Lubricating Oils and Their Effects on Steel. *Petroleum Z.*, 23:1515-1518.		*C.A.* 22:1467
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996		GOODING, F. E., Reclamation of Lubricating and Insulating Oils. *Ind. Eng.*, 85:267-271.		
997		MCRAE, R., Making New Oil from Old. *Elec. Traction*, 23:135-136.		
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LUBRICATION OF BEARINGS

Oil Flow in Bearings. Maintenance of Oil Film

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1000	1920	HYDE, J. H., Report on the Characteristics of the Flow of Oil over a Journal Bearing. Report of Lubricants and Lubrication Inquiry Committee, 1920, pp. 113-114. (Appendix 16.)		
1001	1922	SCHENFER, C., Stability of the Oil-Film in Bearings. *Arch. Elektrotech.*, 11:129-130. (Correction, *ibid.*, p. 268.)		
1002	1923	HELDT, P. M., Opinions Vary Regarding Usefulness of Oil Grooves. *Automotive Ind.*, 49:800.	212c	
1003	1924	STANTON, T. E., Lubrication of Grooved Bearings. *Iron Age*, 113:505.		
1004	1925	DUFFING, Motion of Fluid between Journal and Bearing. *Electrotech. Z.*, 46:272-273. (Abstract of paper given in *Z. angew. Math.*, 4:296-314; 1924.)		
1005		DUGUID, J., Lubricants and Lubrication. *Mech. Eng.*, 47:887-894.		
1006	1926	KARELITZ, G. B., Charts for Studying the Oil-Film in Bearings. *Mech. Eng.*, 48:128-131. 5 Figs.		
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1008		RATHBUN, B., Matter of Viscosity in a Lubricating Oil and Its Relation to Lubrication. *Petroleum Age*, 18:50-51.		
1009		HAYASHIDA, T., Lubrication of High Speed Journals. *J. Soc. Mech. Eng. Japan*, 29:319-373.		
1010		BARNARD, D. P., 4TH, Oil Flow in Plain Bearings. *Ind. Eng. Chem.*, 18:460-462.	224	

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1012		HAVRE, H., The Theoretical and Practical Study of Lubrication. *Genie Civil*, 90:45-48. Abstract in *Mech. World*, 82:397.	225	
1013		BROOKS, D. B., and SPARROW, S. W., Oil Flow Through Crank-Shaft and Connecting Rod Bearings. *J. Soc. Automotive Eng.*, 21:127-134.		
1014		NEWTON, H. J., Semi-Annular Grooves in Bearings Urged as Lubrication Aid. *Automotive Ind.*, 57:54-56.		
1015		STANTON, T. E., The Lubrication of Surfaces under High Loads and Temperatures. *Engineering*, 124:312-313.		
1016		VIEWEG, R., and VIEWEG, V., On the Formation of the Oil-Film in Oscillating Bearings. *Maschinenbau*, 6:234-235.		
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1018	1918	HILLIGER, Investigations on the Problem of Steam-Engine Lubrication. *Z. Ver. deut. Ing.*, 62:173.		
1019	1923	DUFFING, H., New Ring Lubricator for Axles of Railroad Cars. *Verkehrstech.*, 40:232-233.		
1020	1926	GOODING, F. E., Problems in Lubricating Conveyors. *Ind. Eng.*, 84:513-517.		
1021		BROMLEY, C. H., New Methods of Lubricating Steel Mill Machinery. *Mech. Eng.*, 48:1344-1346. *Mech. World.* 2 Figs.		

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1025		FRIEDRICH, W., The Economic Advantages of Mechanical Bearing Lubrication for Railroad Practice. *Org. Fortschritte Eisenbahn.*, 82:125-126.		
1026	1927	BLANCHARD, E. P., Machine-Tool Lubricating Systems. *Am. Machinist*, 66:607-608.		
1027		HORNER, F., Lubricating Machine Tool Bearings. *Can. Machinery*, 38:15-18.		
1028		KARELITZ, G. B., The Lubrication of Waste-Packed Bearings. *Mech. Eng.*, 49:663-670.		
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1030		TYPKE, DR., Notes on Rational Oil Economy. *Maschinenbau*, 6:216-219.		
1031		WHITE, R. B., Problems of Motor-Car Lubrication. *Oil Gas J.*, 25:143-144.		
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1033		ANONYMOUS. Use and Application of Graphite in Lubrication. *Belting*, 30:42-46.		
1033a		MOUGEY, H. C., Oil Lubrication for Automobiles. *Oil Gas J.*, 26, No. 25:96A-B, 136.		*C.A.* 22:682
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TESTING LUBRICANTS AND BEARINGS

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1035	1898	KAPFF, S., Testing of Lubricating Oils, Especially Spindle Oils, with a New Oil Tester. *Z. Ver. deut. Ing.*, **42**:553-558.		
1036	1902	KINGSBURY, A., A New Oil Testing Machine and Some of Its Results. *Trans. Am. Soc. Mech. Eng.*, **24**:143-160.		
1037		DETTMAR, G., An Apparatus for the Investigation of Oils and Bearing Metals. *Elektrotech. Z.*, **23**:731-745.	227	
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1040	1922	HOLDE, The Examination of Hydrocarbon Oils and Saponified Fats and Waxes. New York, John Wiley & Sons, Inc., **1922**, 5th Ed.		
1041	1923	DALLWITZ-WEGENER, R. VON, "Chemische-technische Untersuchungsmethoden." G. Lunge, Berlin, Julius Springer. 7th Ed., p. 467.		

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1043	1924	HOLDE, D., Kohlenwasserstofföle und Fette. Berlin, Julius Springer. 6th Ed., p. 188.		
1044	1923	JOHNSTONE-TAYLOR, F., Testing Bearing Metals and Lubricants. *Am. Machinist*, **58**:700.		*J.*30:599
1045		VIEWEG, V., and VIEWEG, R., Separation of Air and Bearing Friction. *Maschinenbau*, **3**:143-145.		*J.*34:574
1045a		AM. SOC. TESTING MATERIALS, SUB-COMMITTEE XI ON EMULSIFICATION. (Report.) *Proc. Am. Soc. Testing Materials*, **23**(1):358-362.		
1045b		DIMMIG, H., Method of Measuring the Emulsifying Tendency of Lubricating Oils, Based on Surface Tension. *Proc. Am. Soc. Testing Materials*, **23**(1):363-373.		
1046	1924	DALLWITZ-WEGNER, R. VON, On the Measurement of the Lubricating Capacity of Lubricating Oils. *Z. tech. Phys.*, **5**:378-384.		
1047		DALLWITZ-WEGNER, R. VON, A Novel, Simple and Universal Method for the Investigation of Lubricating Oils and Bearing Oils. (Amsler.) *Testing*, **1**:58-71.		*C.A.*18:1902
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1049	1926	DALLWITZ-WEGNER, R. VON, A New Simple-Scale Viscometer. *Petroleum Z.*, **22**:1058-1059.		*C.A.*21:2184
1050		SPINDEL, M., Testing of Lubricating Oil with Regard to Power and Wear of Machines. *Petroleum Z.*, **22**:584-586, 610-619; *Sparwirtschaft*, Nos. 2 and 3, pp. B21-B25, B43-B48.		*C.A.*21:1181 *C.A.*21:2184
1051	1927	MARSHALL, A. G., and BARTON, C. H., Lubricating Oils; Laboratory Tests in Relation to Practical Results. *Engineering*, **123**:435-439.		

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1051b	1927	ERK, S., Viscosity Measurements on Liquids and Investigations of Viscometers. (Communication from Physikalische-Technische Reichsanstalt.) *Forsch. No.* 288, 54 pp., 27 Figs., 11 Tables; *Z. tech. Physik.,* 18:595-599; *Z. Ver. deut. Ing.,* 72: 11-14 (1928).		*C.A.* 22:896
1051c		HILLIGER, Testing of Lubricants in Germany. *Internl. Cong. Testing Materials Amsterdam,* Vol. II, pp. 437-446.		
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1051e		MATTHIS, A. R., Contribution to the Study of Oils for Turbines, Oils for Transformers, and Oils for Autos.—Rapid Selective Test. *Internl. Cong. Testing Materials, Amsterdam,* Vol. II, pp. 469-478.		
1051f		WOOG, P., Observations on the Measurements of Coefficient of Friction of Lubricating Oils. *Internl. Cong. Testing Materials Amsterdam,* Vol. II, pp. 409-414.		
1051g	1928	BACON, F. S., Determination of Unsaturateds in Lubricating Oils. *Ind. Eng. Chem.,* 20:970-971.		
1051h		HILL, J. B., and COATS, H. B., The Viscosity-Gravity Constant of Petroleum Lubricating Oils. *Ind. Eng. Chem.,* 20:641-644.		*C.A.* 22:2834
1051i		MASTERS, E., and GODDARD, A. E., Apparatus for Determining Viscosity under Varying Conditions. *Ber.,* 61B, 586-591.		*C.A.* 22:1876
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Measurement of Oiliness

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1054	1926	GILL, A. H., and GILL, H., A Possible Test for the Oiliness of Oils. *Ind. Eng. Chem.*, 18:527.		
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Measurement of Oil-Film Thickness

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1057		WADSWORTH, F. L. O., A Determination of the Specific Resistance of Oil in Thin Films and the Application of These Results to the Measurement of the Thickness of the Oil Film in Journal Boxes. *Phys. Review*, 5:75-97.		
1058	1903	KENNELLY, A. E., and ADAMS, C. A., The Electrical Resistance of Bearings. *Elec. World Eng.*, 41:231.	229	
1059	1916	DE FOREST, A. V., Some Experiments in Lubrication. *Engineering*, 101:509.	230	

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1061	1927	SCHERING, H., and VIEWEG, R., On the Estimation of Bearing Lubrication by Electrical Measurements. *Z. angew. Chem.*, 39:1119-1123, 1601; 1926. *Wiss. Abh.* P.T.R., 10:337-351. (Reprint.)		*C.A.* 20:3802 *C.A.* 21:1545
1062		VIEWEG, V., Measurement of Oil-film Thickness in Bearings. *Verkehrstech.*, p. 858. (Abstract.)	231	

Testing Finished Bearings. Service Tests

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1064	1905	ANONYMOUS. The Experimental Determination of the Relative Value of Short Bearings. *Am. Machinist*, 28(2):878-879.	232	
1065	1910	McDERMID, H. B., An Investigation of Bearing Metals. *Am. Machinist*, 33(2):1054-1057.		
1066	1925	FEIFEL, E., A Test Stand for Large Thrust Bearings. *Z. Ver. deut. Ing.*, 69:679-683.		
1067		ANONYMOUS. Endurance Tests on Bearing Metals. *English Mech.*, 121:243.		
1068		CHRISTIANSEN, S. A., First Full Throttle Endurance Test of Liberty Engine Equipped with Various Experimental Materials. *U. S. Air Service Information Circular, No.* 523 (Vol. 6). 31 pp. *McCook Field Serial Report No.* 2490.		
1069	1926	JOACHIM, W. F., and CASE, H. W., Tests of Several Bearing Metals Lubricated with Gasoline. *Natl. Advisory Comm. Aeronautics Tech. Notes, No.* 241, July. 19 pp. 3 Figures.		

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1071	1927	ENDE, E. v., Bearing Testing. *Verkehrstech.*, p. 858. (Abstract by Przygode.)	233	
1072		ANONYMOUS. Machine Devised by the Compagnie des Chemins de Fer de l'Est for Testing Lubricating Oils and Antifriction Alloys. *Bull. Soc. Eng.*, 126:444-449.		C.A. 21:3492
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PART 3

ABSTRACTS OF SELECTED PAPERS

ABSTRACTS OF SELECTED PAPERS

1. **Bearing Metal Alloys.** C. B. Dudley, *J. Franklin Inst.*, **133**:81-93, 161-172 (1892).

The author illustrates the importance of obtaining a low-wear bearing metal by referring to the fact that a railroad bearing may lose 1 pound in weight per 25,000 miles. He states that it is a common belief that two metals of the same kind will not work well together in a bearing.

Dudley states the characteristics of a good bearing metal:

(1) The compressive strength should be sufficient to stand bearing loads of 350-400 pounds per sq. in. Compressive stresses are greatest when a new bearing is installed with an old shaft. However, as the practice is to line the bearing with one-eighth inch of lead, the shaft soon seats itself. (2) Bearing metals should not heat easily. The softer the alloy the less is the tendency to heat. (3) The metal should work well in the foundry. Oxidation should be prevented. Zinc or phosphorus helps to produce sound castings. (4) The metal should have a low coefficient of friction though this is partly a property of the oil. (5) The metal should have a low rate of wear.

The author gives the compositions of some of the bearing metals in common use.

Service tests on the Pennsylvania Railroad are described: A standard and an experimental bearing were installed on either end of an axle of various rolling stocks. The bearings were weighed before installation and after a definite time. A mileage basis was used at first, but later simply a standard *vs.* an experimental. The standard metal used was the "S" phosphor bronze, *viz.*, Cu, 79.7: Sn, 10; Pb, 9.5; P, 0.8. The "S" bronze lost about 1 pound per 18,000 or 25,000 miles. The mileage basis was not used as the conditions were not the same in all the cases, though the bronze itself was uniform in quality.

The behavior to heating was also compared but no measurements of friction were made. The results of some of the tests are given in the accompanying table.

Comparison of Standard and Experimental Bearings.

Name	Cu	Sn	Pb	P	As	Relative Wear
			Composition			
Standard "S"	79.7	10.0	9.5	0.8	...	1.00
Arsenic Bronze	79.7	10.0	9.5	...	0.8	1.01
7/1 Bronze	87.5	12.5	...	...	...	1.47–1.53
Arsenic Bronze	89.2	10.0	...	...	0.8	1.42
Arsenic Bronze	79.2	10.0	7.0	...	0.8	1.15
Ex. K Bronze.........	77.0	10.5	12.5	...	...	0.92–0.93
Ex. B Bronze.........	77.0	8.0	15.0	...	...	0.865

The above compositions are average, no allowances being made for small amounts of Zn, Fe, Sb, etc. A much larger per cent of the 7/1 bronze heated than of the "S". With arsenic bronze due to fact that arsenic may practically take the place of phosphorus, neither element has much effect in reducing wear. Phosphorus seems to be more valuable in the foundry than in service. No heating trouble was had with the "K" bronze and the rate of wear was much lower.

After some experimenting, a copper to tin ratio of 9.5:1 was decided on as giving the best results as far as bearings were concerned. Some evidence was found that the copper could be decreased still more. The addition of lead had the same effect as the diminution of tin. Ex. B metal had a tensile strength of 24,000 pounds per sq. in. against 30,000 pounds per sq. in. for "S", while the elongations are 11 per cent and 6 per cent respectively. Ex. B metal has been put into service on the Pennsylvania Railroad as the standard bearing metal with a slight modification, *i.e.*, the addition of phosphorus in the foundry, to enable the utilization of a large amount of phosphor-bronze scrap. The lead might be increased to advantage, but apparently a certain amount of tin is necessary to prevent lead segregation. Ex. B metal seems to be about the limit in this direction.

The formula in use on the Pennsylvania Railroad is: Cu, 105 lbs.; Phosphor bronze (new or scrap), 60 lbs.; Pb, 25¼ lbs.; Sn, 9¾ lbs. The Cu and bronze may be put in the melting pot before placing on the melting hole, the Sn and Pb after removing from the fire.

Dudley's conclusions are: (1) "That metal which will suffer the most distortion without rupture is the one which will wear the best". This quality is usually expressed in figures by the elongation in the tensile test. (2) Given a satisfactory elongation an increase in the tensile strength will add to the wearing power of the metal, *i.e.*, the particles of metal would be harder to tear off. Bearings wear three times as fast as axles, but the latter have two to three times the tensile strength and a somewhat higher elongation. (3) The metal with the

finer grain will have the lower rate of wear. Few data on this point are available.

2. A Study of Alloys Suitable for Bearing Purposes. G. H. Clamer, *J. Franklin Inst.*, 156:49-77 (1903).

The author classifies white metals into eight classes and bronzes into five. This paper is limited to alloys suitable for railroad journal bearings. The following points are essential:

(1) *Composition.* If adjustment could be perfect composition would be of little importance as there would be no metal to metal contact. This is not the case in practice, however, especially where reversal of motion occurs.

(2) *Structure.* This depends mostly on the composition, though heat treatment may affect the size of the crystals. It has been shown that a duplex structure is necessary in the case of a bearing metal. In general the harder the surface, the lower the coefficient of friction and the lower the load at which seizure occurs. In view of this, Cu-Sn alloys were used in the early days of railroading, but were unsatisfactory as the requisite degree of adjustment could not be maintained. Hopkins introduced lead-lined bearings, but a certain degree of plasticity was still necessary in the back. To secure this, lead was introduced into the Cu-Sn alloy.

(3) *Friction.* The harder the metal the lower the friction, but the greater the tendency to heat, because of the absence of plasticity.

(4) *Running Temperature.* The higher the temperature the greater the oil consumption, although the friction is less, provided conditions are normal. (High temperature may be caused by friction.) In general bronze will operate at a lower temperature than white metal.

(5) *Wear of Bearing.* The relation between wear and composition presents a wide field for research that is practically unexplored.

(6) *Wear of Journal.* It is generally conceded that soft metal bearings cause a marked decrease in the life of journals. The author quotes Van Alstine, who attributes the short life of English truck axles to the fact that they are run on babbitted brasses.

(7) *Compressive Strength.* A test of compressive strength is of importance in indicating: (a) If the alloy is hard enough to support the load without deformation. (b) If the alloy is brittle and will split under effects of pressure. (c) If it is sufficiently plastic to suppose reasonably that it will run cool under aggravated conditions.

CLASSES OF ALLOYS.

Pb-Sb. These metals alloy in all proportions, the hardness and brittleness increasing with the Sb content. The only alloy of this system exempt from segregation is the eutectic Pb, 87; Sb, 13, which has a laminated structure. If Sb is below 13 per cent, Pb is in excess; while if Sb is over 13 per cent, Sb crystals appear which rise to the surface if the melt is slowly cooled. (Density of Sb = 4.5, density of eutectic = 10.48.) Charpy claims that the alloys with 15-25 per cent Sb are best for bearings, but the author does not quite agree with this. Although the friction is greater below 13 per cent Sb, the wear is less if the load is light. Here alloys with 8-12 per cent Sb are much superior, not having to be renewed so often. According to our work, Pb is the best wear-resisting metal and wear increases with Sb content along with the hardness and brittleness. This is due to the splitting up of the harder particles. Friction decreases with an increase in Sb content. Journal wear is probably due to the fact that the worn-off particles of the steel become embedded in the bearing, causing it to act as a lap.

Pb-Sb-Sn. For high pressures, Sn is a very valuable addition to a bearing metal. It gives the alloy rigidity and hardness without increasing the brittleness. Complete structure of the system has not been worked out to date. Besides the metals in a pure state there is also present the compound SbSn which, occurring in cuboid crystals, gives a coarser structure to the fine-grained antimonial lead of commerce.

Sn-Sb. The structure from 5 to 45 per cent Sb is free Sn in a matrix probably composed partly of SbSn or $SbSn_2$. These alloys are seldom used for bearing metals.

Sn-Sb-Cu. Genuine Babbitt—Sn, 89.1; Sb, 7.4; Cu, 3.7—is due to Isaac Babbitt (1839), the first man to conceive of lining bearings with a fusible metal. It is the standard of excellence, but is often used where a cheaper metal would do as well. The structure is: cuboid crystals Sn, 90; Sb, 10, and a white bronze Sn, 90; Cu, 10, forming radial clusters or bright rods composed of hexagonal flakes. The matrix is nearly pure Sn.

Sn-Sb-Pb-Cu. Pb in small amounts renders the alloy harder, stiffer, lowers the melting point and improves it in every way.

The above white metals are more important than those containing Zn. Zn tends to adhere to the steel journal even when slightly heated. Zn alloys also tend to become brittle when heated.

BRONZES.

The author gives a description of the Carpenter friction testing machine which he has used for testing a series of bronzes. The journal was lubricated by means of waste held to the under side.

Cu-Sn. Up to 30 per cent the alloy is hardened by Sn, but above this the alloy becomes more like Sn. Bearing alloys lie between 3 and 15 per cent Sn. If the Sn is above 15 per cent there is no plasticity, and seizure occurs if the adjustment is not perfect. The alloy which is least liable to heat and cause trouble is the one which will stand the greatest amount of abuse. Enthusiasts for hard metals have even proposed glass bearings. These might give satisfaction as the jewels of a watch but would hardly stand locomotive service.

Cu, 85; Sn, 15. The structure is: $SnCu_3$ crystals, pure Cu dendrites and a large area of the eutectic Cu, 73; Sn, 27. It has the lowest friction and wears the fastest of the Sn bronzes tested.

Cu, 90; Sn, 10. This has a greater amount of Cu and a lesser amount of eutectic.

Cu, 95; Sn, 5. This has a large amount of Cu and a small amount of eutectic. It has the highest friction and the lowest rate of wear.

Dudley, to whom, more than any one else a sound knowledge of bearing bronzes is due, says, "The rate of wear diminishes with diminution of Sn" (see Abstract No. 1). The author's work confirms this.

Cu-Sn-Pb is now recognized as the standard bearing metal. It is less liable to heat and wears less. Results of tests on this system are tabulated. The author's work is merely confirmatory of past researches. As and P apparently have no effect on the wearing qualities.

Cu, 90; Sn, 5; Pb, 5. The structure is pure Cu, pure Pb held mechanically, $Cu + SnCu_3$ eutectic or possibly a double eutectic.

Cu, 85; Sn, 5; Pb 10 and *Cu, 80; Sn, 5; Pb 15* have a similar microstructure but with increasing amounts of free Pb.

It seems desirable to obtain alloys with as high a lead content as possible. The best Dudley could do was his Ex. B alloy: Cu, 78; Sn, 7; Pb, 15. Dudley found that a certain amount of Sn was necessary to hold the Pb in the Cu.

The author and his associates found experimentally that a certain amount of Sn was necessary to prevent Pb segregation and also to give the alloy the requisite compressive strength, but that a greater amount of Sn was detrimental. "We were able to produce Cu, 65; Pb, 30; Sn, 5, but not Cu, 63.5-64; Pb, 30; Sn, 6-6.5; nor could we produce

a casting containing over 20 per cent Pb if the Sn was more than 7 per cent.

This seems strange, as the reverse would be expected. The most satisfactory explanation seems to be that contained in the claims of the patent which covers this alloy. As the amount of eutectic increases with the amount of Sn, the freezing time is also increased and consequently the Pb has a greater chance to segregate.

If no eutectic is present, solidification takes place soon after pouring into the mold and entraps the still liquid Pb. The proportions given in the patent might be deviated from for small castings, but for large scale work, the only satisfactory results can be obtained with Pb over 20 if the Sn is less than 7 per cent.

As chill castings are not always practicable, it is desirable to find some additional way of making the alloy set quickly for use in the case of sand casting. Nickel from 0.5 to 1 per cent was found to do this.

This alloy called "Plastic Bronze" is now a commercial article, over 4,000,000 pounds being produced in the last three years. Some castings weighed over 1000 pounds. The author claims the castings are sharp, clean and easy to machine. He gives the results of a series of friction tests.

The alloy adopted for the best from all points of view, consistent with strength and best foundry results is Cu, 64; Sn, 5; Pb, 30; Ni, 1. This alloy possesses plasticity, resembling babbitt. It has proved satisfactory in service.

Several other classes of bronzes contain Zn, and are frequently made from junk. Zn, however, is not desirable as it increases the rate of wear and tends to segregate the Pb. Wear tests are tabulated. Such metals form a large part of the railroad equipment in bearings.

We have recently put in operation a patented process for refining Cu-Sn-Pb alloys containing Zn and other electropositive metals.

3. Bearing Metals. A. Hague, *Engineering*, 89:826-829 (1910).

The author lists the most important properties of bearing metals:

(1) *Coefficient of Friction.* The metal should have a low coefficient of friction, and its surface should be highly finished, for only in this way can static friction be reduced. In this respect, there should be, as nearly as possible, an approach to rolling friction. Beyond a certain low speed, about 10 feet per min., the advantage of a roller bearing ceases, and a theoretically perfect journal bearing should

not have a higher coefficient of kinetic friction than any other type. As the speed increases there should be a sudden drop in friction at 10 feet per min. Tower shows that this is due to the formation of an oil wedge forcing the surfaces apart and preventing metallic contact. In the ideal case the friction is essentially fluid friction, but this is rarely attained in practice, and the bearing metal has to reveal its qualities.

It should be mentioned that a bearing should incline gradually from the point of no pressure, where the oil enters, to the point of maximum pressure, where the film needs to be thickest.

Above a certain pressure oil is squeezed out, metallic contact occurs and the properties of the bearing metal are best demonstrated.

(2) *Compressive Strength.* The metal should have sufficient compressive strength to withstand high pressure. The compressive strength should not be less than 9000 pounds per sq. in. for white metals, and not less than 13,000 pounds per sq. in. for metal for connecting rod bearings.

The harder the bearing metal the less the friction if the load is evenly distributed, and the greater the load causing seizure. This led to the introduction of bronzes which were unexcelled up to about 1890.

(3) *Durability.* It is important for a bearing metal to have a low coefficient of friction and a high degree of durability. The slowest wearing metal may have the highest coefficient of friction. This is exactly the case with lead. For low running temperature, it is well to avoid lead entirely.

(4) *Low Running Temperature.* Where this is important, as in the case of high speed machinery, it is necessary to use a metal of low specific heat and high thermal conductivity. High tin alloys are better than high lead alloys in this respect.

(5) *Minimum Wear of Shaft.* White metals are superior here as they do not score the shaft if the lubrication is insufficient.

(6) *Good Behavior under Irritating Circumstances.* This chiefly concerns the safeguarding of the shaft from deterioration.

(7) *Ease in Fixing and Replacing.*

(8) *Resistance to Corrosion.* This applies especially to that of the lubricant. Sn and Sb resist entirely, Fe, Cu, Pb, and Zn corrode in the order named, Zn being quite the worst.

(9) *Cost.*

In preparing a new alloy, a close agreement between coefficients of

expansion of the shaft and the bearing should be aimed at, as on heating the bearing is liable to seize.

RIGID BRONZES.

When well fitted, these will run cooler and with less friction than any other bearing metals. They will also stand greater pressure, though this is of little importance, for beyond a certain pressure, which white metals and plastic bronzes can easily withstand, lubrication is interfered with, and dry bearings are rarely used. On the other hand, these bronzes wear the most of all, which has caused them to be replaced in America largely by plastic bronzes or white metal-lined bearings.

The hardness of true bronzes increases with the amount of tin, but 20 per cent is about the limit. If the tin content is greater than this, the alloy is too brittle to be satisfactory.

Bronzes with over 6 per cent Sn consist of a portion high in Cu, surrounded by a high Sn eutectic. This latter is very hard. The former is a solid solution of Sn in Cu and solidifies first. The eutectic probably forms the principal bearing surface, but when it forms too large a proportion of the alloy, this becomes brittle.

Bronze is notoriously difficult to cast, and to improve it in this respect the general practice is to add 1 to 2 per cent Zn. This probably acts as a mild deoxidiser, and in any case makes the metal more fluid, gives soundness to it and better machining qualities.

Admiralty gun metal (Cu, 88; Zn, 10; Sn, 2) is used in the Birmingham power station for small unimportant bearings, and with white metal linings for all others. Zn up to 14 per cent is used as a cheapening addition, but cannot be recommended for good work as it makes the alloy wear badly. The introduction of phosphorus as a deoxidiser is a decided improvement, as it makes the alloy closer grained, harder and more homogeneous. Si is also used for this purpose. Arsenic is sometimes used as a deoxidizer, but possesses no especial advantage, and is dangerous to use in the foundry.

It used to be the practice to add 1-2 per cent phosphorus to the new metal with view of gradual reduction on subsequent remeltings. Such alloys, however, gave bad results. It was found that phosphorus did not appear to decrease on remelting. In the first casting a very stable phosphide was formed, which segregated on remelting to form bunches of very hard crystals throughout the alloy. These cut the journal badly and caused excessive heating. Therefore it is essential

to have just sufficient phosphorus to oxidize the impurities and to pass into the slag. Any excess is to be avoided.

The great disadvantage of rigid bronzes is their lack of plasticity. The surface is worn only at the expense of almost certain deterioration of the shaft or axle, leading to heating.

PLASTIC WHITE METALS.

In the case of modern high class stationary engines, with very perfect forced lubrication, the nature of the metal is of little consequence as far as antifrictional or wear properties are concerned, but the use of white metal linings allows of easy, accurate adjustment and the lining molds itself under the pressure so that it presents its whole surface to the load. In the case of overheating, the white metal may partially fuse without damaging the shaft.

Lead linings were introduced by Hopkins but were found to be too plastic for this purpose. Sb was used as a hardener. Ternary alloys of the system Pb-Sb-Sn were found to be better than straight antimonial lead. Although these alloys do not get rid of the heat developed as rapidly as bronze, the advantages of a plastic metal may be obtained if larger or longer bearings are used. Also, high tin white metals are little behind bronze in regard to heat dissipation.

The name "antifriction" applied to white metals is somewhat of a misnomer as they have higher coefficients of friction than bronze. The name is due rather to the decrease in the number of hot boxes resulting from their use. In railroad service, the number of hot boxes with white metal linings was less than half that with bronze boxes.

Both plasticity and hardness are obtained by a duplex structure of hard grains embedded in a plastic matrix. These grains wear slightly in relief and serve to distribute the oil evenly over the surface.

Pb-Sb. The useful range is 13-25 per cent Sb. The friction decreases with Sb and the rate of wear increases. Hardness is obtained only with a certain degree of brittleness, and wear takes place by splitting of the harder grains.

Sn-Sb. These alloys contain cubic crystals of the compound SnSb, which are not as brittle as pure Sb, though nearly as hard. The compound also enters the matrix and gives the alloy a high compressive strength. These alloys are rarely used in practice, being no more satisfactory than some of the cheaper ternary alloys.

Sn-Sb-Cu. This system includes genuine babbitt, which has the highest compressive strength of any satisfactory bearing metal and

runs at the lowest temperature, resulting in a saving of oil. The alloys consist of crystals of a Cu-Sn compound, the SnSb cubes of the previous system, and a Sn rich matrix containing 95-97 per cent Sn. If lightly polished with an abrasive powder, say rouge, the Cu-Sn stands slightly in relief, while if considerable pressure is applied, as in the case of a bearing which has been in service some time, the cubes stand in relief. This is probably due to the disintegration of the needles under pressure. The Cu-Sn needles seem to have a sub-surface function in helping to stiffen the matrix. If the Sb is less than 4 per cent, no cubes are formed, and if the Sn is less than 2 per cent, no needles are formed. The limiting range in practice is Cu, 2-10 per cent; Sb, 8-15 per cent. If the Cu is greater than 10 per cent or the Sb greater than 15 per cent, the alloys are too brittle.

Pb-Sb-Sn. By the addition of Sn to Pb-Sb, the brittleness of the Sb grains is modified by the presence in solid solution of the compound SbSn. This compound also hardens the matrix and increases the compressive strength. The rate of wear is less than that of Sn-Sb-Cu. Heat is not dissipated as rapidly as in the high Sn alloys, therefore the system is not recommended for high speeds. The compressive strength is comparatively low, between that of Pb-Sb and genuine babbitt. The financial limit to Sn is 45 per cent and the practical limit to Sb is 20 per cent. They should contain at least 10 per cent each of Sn and Sb.

Pb-Cu-Sb. Sb prevents segregation if the Cu is not over 10 per cent. The compound $SbCu_2$, which crystallizes in needles, is formed and is also found in the matrix as a toughening constituent. Cubes of Sb, if this is not under 15 per cent, fulfill the greater part of the bearing duty. The practical range is Sb, 14-25 per cent; Cu, 4-10 per cent. These alloys are not largely used, as the compressive strength is low and they tend to segregate.

Sn-Zn-Sb. The constituents are: Zn, Sn and a compound of Zn and Sb. The latter is the hard constituent and should crystallize out first. Primary crystallization of Zn is to be avoided as Zn grips the shaft easily. Alloys in which the compound crystallizes out first contain 10-15 per cent Sb and 10-15 per cent Sn. Sn helps to diminish the brittleness. The remarkable point of these alloys is their high compressive strength. They are comparatively cheap, but difficult to cast. The volatility of Zn is aggravated by the presence of Sb. Zn is rapidly coming to be recognized as an undesirable constituent for four reasons: (a) it is easily corroded by lubricant; (b) it galvanizes

the journal; (c) overheating causes brittleness; (d) its wear is relatively great.

Arsenic is often used up to 1 per cent. It produces a fine-grained fracture and castings free from blow-holes, which probably accounts for the extensive sale of such alloys although their wearing qualities are decreased and they are less hard and tough. P, KCN, and Na are also used to small extent. Hg up to 5-6 per cent has been used for ship propeller bearings, probably with a view of resisting wetting. An eminent engineer has recommended the addition of Mn as Cu-Mn for the bearings of hydraulic machinery which are liable to be exposed to chemicals which would corrode ordinary alloys.

Goodman found that the addition of 0.2 per cent Bi to Pb-Sb-Sn decreased the frictional resistance over one-half, but this was increased again on the addition of more Bi. A minute quantity of an impurity reduces friction if the atomic volume is greater than that of the alloy. The converse is also true.

The casting temperature of white metals should not exceed the melting point of Zn as the metal is liable to oxidize, forming hard grains. By casting around a cold core, too great a proportion of the hardening constituents are held in the matrix. Good practice is to preheat the core to 212° F. (100° C.). Chill casting is not recommended as it brings the matrix, which is still comparatively soft (though it is stiffened) too much into prominence as the actual bearing constituent. Chill castings are liable to be brittle and contain internal strains. If the rate of cooling is too slow, the cubes are liable to be too large and tend to segregate. The author cites the work of Behrens on grain size.

PLASTIC BRONZES.

These are not much used in England, though they are used widely in America. According to Charpy the black areas seen under the microscope are cavities filled with Pb crystals. This is confirmed by the fact that the density is less than that computed from the composition. The Pb content of these bronzes has recently been increased up to 30 per cent. The author cites Carpenter's tests. He mentions Dudley's Ex. B metal as the standard bearing metal in this class.

To include more lead than this alloy (Cu, 78; Pb, 15; Sn, 7) contains, contrary to expectation, the amount of Sn must be reduced. If the Sn is reduced to 5 per cent the Pb may be increased to 30 per cent without segregating. This is probably due to the action of the Cu-Sn

eutectic. If Sn is less than 5 per cent, no eutectic is formed and the metal sets soon after entering the mold, thus trapping the Pb. When the eutectic is present it remains liquid a long time after the main bulk of the alloy is solid, giving the Pb opportunity to sink to the bottom. The alloy Cu, 65; Pb, 30; Sn, 5 is now on the market. It is advantageous to cast it in chill molds if this is possible, to guard against segregation. If this is impracticable, rapid setting may be induced by the addition of 1 per cent Ni in the form of Cu-Ni. Zn is highly objectionable, as it increases the amount of wear and favors the segregation of Pb.

4. The Nature and Constituents of Bearing Metals. R. R. Clarke, *Brass World*, 10:411-413, 458-460 (1914).

Friction and wear are a direct consequence of motion between metallic surfaces in contact, while heating is an indirect consequence. The frictional heating quality of a metal may be estimated by a hammering test. Pb, when flattened out by quick hard blows, becomes warm, Sn still warmer, Cu and Zn burning hot. Wear consists in the tearing off particles of metal, and heat is developed in their separation. Heat is also developed when molecular distances are changed by hammering.

Equality of action and reaction prohibits making the journal and the bearings of the same material. Their ease of renewal decides that the latter shall take the wear.

Cu is the chief constituent of bearing metals as distinguished from lining metals, though few metals are less suitable than pure Cu. The addition of Sn gives strength and reduces the malleability and the adhesive qualities. The addition of Pb renders the alloy antifrictional and plastic, though it makes the task of the foundryman more difficult. In quantities above 4 per cent, Pb segregates if other elements or special methods are not used. The author has little faith in the addition of Ni, or Fe-Mn, or in alloys containing over 20 per cent Pb. The use of S presupposes special foundry methods. A lining metal containing up to 60 per cent Pb may be used, though above 4 per cent the union is merely mechanical, and it is realized only by continual stirring. Stirring may eliminate segregation but not Pb sweat. This latter is caused by the already solidified Cu contracting and squeezing out the still liquid Pb.

Types of bearing metals were developed in the following order:

Cu-Sn, Cu-Sn-Pb (Sn = Pb), Cu-Sn-Pb-P, Cu-Pb-Sn (Pb > Sn), Cu-Pb-Sn-Ni.

The author mentions Ex. B metal though not by name, also the critical ratio Cu:Sn = 91:9 discovered by Clamer. The author does not involve himself in this argument except to say that Clamer's point seems to be confirmed.

Ex. B metal gives foundrymen less difficulty than some of the newer Cu-Pb-Sn alloys, and yields more homogeneous castings. Alloys with high Pb overtax the best foundry practice. These alloys are easily oxidized and P may be used as deoxidiser only if the alloys contain less than 15 per cent Pb.

Ni hardens and strengthens the alloy. The author has had no experience with foundry difficulties due to its use.

Due to mechanical conditions linings are sometimes necessary. Pure Sn has some value as a lining metal in spite of its adhesive qualities. The author gives some bearing metal formulas.

5. The Chemist and the Brass Founder. R. T. Rolfe, *Proc. Brit. Foundrymen's Assoc.*, 12:88-108 (1914-1915).

This article is a lecture on the properties of, and the manufacture of Admiralty gun metal and bearing metals. The proper structure for a bearing metal is one of hard grains embedded in a plastic matrix. Therefore we should alloy a soft metal such as lead with one capable of forming hard compounds, which crystallise out in the ground mass.

A phosphor bronze used for electrical machinery bearings, viz. Cu, 85; Sn, 14.4; P, 0.6 is considered. The structure is very similar to that of Admiralty gun metal and contains the compound Cu_4Sn. (Ultimate tensile strength = 11-14 tons/sq. in., elongation (in tensile test) = 10-1 per cent). When the P content is vore 0.2 per cent, Cu_4Sn is mixed with CuP, forming possibly a double eutectic. The matrix is a solid solution of Sn in Cu and is the softest constituent. The CuP is the hardest. The matrix is much harder than that of the Pb and Sn base alloys and tends to score the journal when used in a bearing, therefore it should be used for this purpose only where it is possible to have extreme accuracy of adjustment. It has great hardness and resistance to wear and a low coefficient of friction. The soft parts wear down leaving the hard CuP in relief. It is not suitable for bearings of a long shaft supported in several places. Pb may be added to phosphor bronze and the matrix will contain particles of segregated lead.

For engine bearings, an important bearing metal is Admiralty white

metal: Sn; Sb, 8-9; Cu, 2-7 per cent. Two compounds are present, SnSb cubes and Cu₃Sn needles. The hardness increases with the Sb content. If the cubes become numerous enough to touch each other they take part of the load and the alloy will be a brittle one. Addition of Sn to alloys of the binary system Pb-Sb increases the rigidity and hardness. Pb-Sn-Sb alloys are not really satisfactory for heavily loaded bearings. A brittle eutectic of all three metals may be present. The SnSb cubes do not occur if the Pb content is greater than 81 per cent.

The above white metals must be rapidly cooled to prevent segregation but too rapid cooling produces a too fine structure, the metal being practically homogeneous.

6. Bearing Metals and Their Technological Application. J. Czochralski, *Z. Metallkunde*, 12:371-403 (1920).

This paper discusses the properties and preparation of five bearing alloys: (1) A Cu base alloy containing 10 per cent Sn and Zn, Pb, P, etc.; (2) a tin base white metal containing 15 per cent Sb, 5 per cent Cu, Pb, etc.; (3) a lead base white metal containing 15 per cent Sb, 5 per cent Sn; (4) a Ba bearing alloy containing 3 per cent Ba; (5) a Ca bearing alloy consisting of Pb with 2.5 per cent Ca plus some Na, Cd, Cu, or Sn.

The structures of all these alloys have not been completely determined as yet. The Cu alloys usually contain a single kind of crystal Cu-Sn, holding the other components in solid solution. The structure of the Pb and Sn alloys has been well cleared up by the work of Heyn and Bauer. The hard crystals in both of these systems are of Sn-Sb and the matrix of α solid solution (Sn + 7.5 per cent Sb) in case of the Sn base alloys; and of a double eutectic in the case of the Pb base alloys. This eutectic consists of Pb + βSb-Sn (10 per cent Sn) and Pb + δSb-Sn (50 per cent Sn).

The necessity for a duplex structure is illustrated by a Cu-Sn alloy, which originally showed harder and softer constituents and was suitable for a bearing alloy. This was then made homogeneous by annealing but when used as a bearing, seizure resulted. For the same reason, large grain size is not desirable. However, not all alloys with heterogeneous structure are good bearing metals.

In the running in of Cu-Sn bearings this occurs by polishing off irregularities, but in the tin base white metals by the yielding of the matrix. The latter are more plastic and less liable to damage the shaft.

Lead base alloys have a lower load capacity which is liable to be still further reduced by the tendency of the lead to concentrate in "islands".

Photomicrographs are given for each of these alloys in the normal and the overheated (coarse-grained) condition.

The Pb base alloys have the greatest tendency to segregation. Cavitation is liable to occur in the Cu-Sn alloys.

Burning produces deleterious effects. A bronze containing tin oxide is brittle and wears rapidly. Repeated melting and the melting of scrap should be done under a layer of charcoal. Bi, As, Sb, Cd, Al, and Fe are probable harmful impurities in bronze.

The same precautions are to be observed in melting tin base alloys. Harmful impurities are Zn and metals of the Al, alkaline earth and alkali groups.

Burning of Pb base metals causes reduction of the Sb content with consequent brittleness and the loss of antifrictional properties. Burning causes a loss of Ca and Ba in alloys containing these metals. Such alloys are also more sensitive to prolonged overheating especially with an excess of air. Curves are given showing the effect on the Brinell hardness number of duration of heating up to 15 hours; the temperatures, however, are not given. In the case of the Ba alloy, damp charcoal is worse than none.

Diagrams are given showing various furnaces, melting pots, molding devices, etc.

The specific gravity of the Cu and Sn base alloys lies between 7 and 9, that of the Pb base alloys between 10 and 11. The shrinkage amounts to about 0.6 per cent for Sn and Pb base alloys, 0.9 per cent for Ca and Ba alloys and 1.5 per cent for bronzes. More care then must be used that linings of Ca and Ba alloys do not become loose after casting. The bearing shell must be roughened and undercut to hold the lining in place. Hammering with a cylindrical peen hammer is also advised to seat linings of these alloys firmly.

Load-temperature curves are given for service tests on the five alloys. The elastic limits in compression are: bronze, 14,000 pounds per sq. in.; Sn base, 2700 pounds per sq. in.; Pb base, 1300 pounds per sq. in.; Ba alloy, 4800 pounds per sq. in.; Ca alloy, 3700 pounds per sq. in. Cylinders of these metals show without cracking the following compressions expressed in percentage: Ba alloy, 56; Cu-Sn, 55; Pb base, 46; Sn base, 33; Ca alloy, 25. Hardness *vs.* temperature curves are given. The hardness increases with the melting point.

Under some conditions of service the Ba alloy compares favorably with the bronzes and white metals. Only about 20 per cent the number of hot boxes were obtained on the locomotives of one railroad as with white metal.

7. A New Bearing Metal. L. Sempell, *Metallurgie*, 4:667-670 (1907).

The choice of a bearing metal should be of importance only when lubrication is incomplete. The author cites explanations of Rennie. A critical load exists, above which the friction increases rapidly. The load necessary to produce scoring is proportional to the hardness, while friction is inversely proportional to the hardness. The use of a very hard surface is of advantage, however, only if lubrication is incomplete and the surfaces are perfectly fitted. The usual reasons for a duplex structure are given.

A bearing metal which is generally recognized to be excellent has the composition: Sn, 83.3; Sb, 11.1; Cu, 5.55. Experiments of Salomon are referred to. For interpretation of the cooling curve see the work of Goerens. The constituents of the alloy are Sn, SnSb, and $SnCu_3$, no ternary compounds being present. The author confirmed the existence of the above compounds.

The author made the following tests: Brinell hardness, and abrasion test. The test piece was mounted on a lever and pressed with a known force against a cast iron disk mounted in a lathe. The disk rotated at 300 revolutions per min., giving a surface speed of 10,000 meters per hour. The load was 60 kilograms, the test piece area 1 sq. cm. The lubricant was oil containing a little powdered emery.

In the course of his experiments the author came upon the alloy Al, 91-94; Cu, 9-6, which offers some promise as a bearing metal. The properties of the two alloys are as follows:

Composition and Properties of Alloys.

Alloy	Melting Point C.	Depth of Ball Impression Mm.	Loss in Weight, cm.^{3}/hr. Grams
Sn, 83.3; Sb, 11.1; Cu, 5.55....	225	1.68	0.01
Al, 91-94; Cu, 9-6............	628	0.81	0.003

8. Aluminum-Copper Bearings. Anonymous, *Engineer*, 112:489 (1911).

Bearings of the alloy Al, 92; Cu, 8 have been used for service up to 50,000 miles on the Northern Railroad of France without a trace of wear. This alloy has proved economical because of the lightness

of the metal. However, in experiments on the Lancashire and York-shire Railroad, difficulty was experienced in properly bedding the bearings to the journals on account of the hard and brittle nature of the alloy. It was hard to prevent heating under normal running conditions.

9. **Experiments with Substitute Bearing Metals at the Laboratory of the Air Service Arsenal in Vienna.** "Praetorius", *Motorwagen*, 23:44-46 (1920).

The results of service tests of substitute bearing metals in airplane engines are given.

Several Al alloys were tried for the main bearings of a 100 horse-power Mercedes. Alloys containing 70-90 per cent Al and 10-15 per cent Cu did not give good service, the bearings burnt and scored the shaft, due to presence of the hard constituent $CuAl_2$. Alloys containing 80-95.5 per cent Al and not more than 3 per cent Cu were satisfactory up to 1200 revolutions per min., but on full throttle the behavior was the same as above.

Bearings of Zn, 54; Sn, 25; Al, 20; Cu, 1 were slightly worn in test but the shaft was badly scored, due to presence of $CuAl_2$. Similar results on Zn, 87.5; Cu, 6.25; Al, 6.15 at 1000 revolutions per min. for 3 hours were obtained. Zn, 76; Sn, 18; Cu, 6 likewise scored the shaft but was little worn itself.

Lead base alloys were tried, both for main and connecting rod bearings. Pb, 13-80; Sn, 6-68; Sb, 3-15.4; Cu, 0-6 proved fairly satisfactory after 50 hours' service. Small cracks appeared in two cases and were ascribed to faulty casting practice.

10. **Aluminium Alloys as Bearing Metals.** Supt. Royal Aircraft Factory, Light Alloys Sub-Committee Report, British Aeronautical Research Committee, 1921, pp. 321-328.

Specimens of three light alloys, *viz.*, Al, 91; Cu, 7; Zn, 1; Sn, 1; Al, 85; Cu, 14; Mn, 1, and Al, 77; Zn, 20; Cu, 3 were tested as bearings in a friction machine. When the temperature is maintained at 120° F. (49° C.) the frictional resistance of these metals is roughly twice that of white metal and the maximum bearing pressure only one-quarter that possible with white metal. Load-friction and load-temperature rise curves are given.

With these alloys a complete film of oil was never present and seizure occurred as soon as lubrication failed in any way.

Tests made in single and eight cylinder test engines at the Royal

Aircraft Factory indicate that as a material for wrist pin bushings both duralumin and Al, 77; Zn, 20; Cu, 3 are satisfactory if the bush is allowed to float in the small end of the connecting rod and on the wrist pin.

11. Duralumin for Gears. R. W. Daniels, *Metal Ind. (London)*, 19:426 (1921). (Paper read before the American Gear Mfrs. Assoc.)

The author described duralumin as an ideal material for worm wheels provided the bearing and wearing qualities were satisfactory. Comparative tests of duralumin against genuine babbitt bearings showed that for shaft speed over 700 revolutions per min. and loads over 200 pounds per sq. in. the duralumin bearings have less friction, remain cooler and show practically no loss of weight under the most severe conditions. It is needless to say that for the lower loads and speeds that babbitt is superior.

A number of duralumin worm wheels have been in service two years without failure on 1 to 3.5 ton trucks.

In the discussion the author pointed out that for casting, duralumin had to be die cast, therefore it was necessary to produce in quantity to compete with bronze. Bearings of this alloy should not be used on soft steel shafts but can be used on hard ones. It does not compare with babbitt but with bronze.

12. Aluminum Base Metal for Motor Bearings Gives Low Cost. A. B. Creelman, *Elec. Ry. J.*, 60:79 (1922).

Bearings of "Elmore U. S. Metal", an aluminum base alloy, wore as well as bronze bearings for one year in electric railway motor service where the use of babbitt was a failure. The net cost of these bearings was only 12 per cent that of bronze.

13. Bronze Bearing Metals. (Symposium on the Conservation of Tin.) G. H. Clamer, *Trans. Am. Inst. Mining Met. Eng.*, 60:162-166 (1919).

The author traces the development of bronze bearings from the old 90-10 alloy which gave much trouble in cutting and heating. Dudley studied the effect of replacing both Cu and Sn partially by Pb. He concluded that the rate of wear diminished with increasing lead content, and with decreasing tin content. The highest lead alloy he succeeded in making, "Ex. B. Metal," was: Cu, 77; Sn, 8; Pb, 15.

It is now possible to produce alloys such as Cu, 65; Sn, 5; Pb, 30 which do not segregate even in large bearings. This alloy does not have great enough resistance to compression for certain mill bearings, where a Cu, 73; Sn, 7; Pb, 20 alloy can be used instead. This, however, is not strong enough for the rod bearings of heavy locomotives, but Cu, 80; Sn, 10; Pb, 10 can be used. The alloy may contain 1 per cent P. The alloy with 30 per cent Pb has given good service in car bearings. (See United States Railroad Administration Specifications.)

If Sb is substituted for Sn, hardness is obtained at the expense of ductility. Castings are not so satisfactory, being rough and showing globules of Pb on the surface. Ni may be used to advantage, Zn is unsatisfactory, and Al worthless.

13a. **Wear and Mechanical Properties of Railroad Bearing Bronzes at Different Temperatures.** H. J. French, S. J. Rosenberg, W. LeC. Harbaugh, and H. C. Cross, *Bur. Standards J. Research*, 1:343-421 (1928).

The results are given of an extensive investigation at the Bureau of Standards on the properties of bearing bronzes. One of the purposes of this investigation was to find a more rational basis for bearing metal specifications than hitherto available. The specifications used by the various railroads vary widely but the limits of composition for any one type are often unnecessarily narrow.

The bearing metals investigated were copper-tin-lead alloys belonging to two groups, one varying in lead and the other in tin. Both sand-castings and chill-castings were made of each alloy. The investigation covered wear tests with the Amsler wear-testing machine, sand abrasion tests, as well as tensile, single-blow impact and pounding tests, at temperatures from 20° to 315° C.

Wear Tests. Wear tests were made under sliding friction both with and without lubrication. A steel disk was rotated (in the Amsler machine) against a bronze specimen of the same thickness, having a depression milled in its side to fit the disk. Rolling friction tests were made by rotating a steel and a bronze disk together in contact and in opposite directions at the same speed. Combined rolling and sliding friction was obtained by rotating the disks at different speeds. The steel disks used were cut from railroad axles; one of which contained 0.37 per cent carbon and the other 0.44 per cent.

In the case of lubricated friction, both rolling and sliding, after a preliminary running-in period in which appreciable wear occurred,

the rate of wear dropped to very low values, which were about the same for all of the alloys. It was found as far as the wearing-in period was concerned that increase in lead content was accompanied by increased wear, work expended and number of revolutions of the steel disk. The figures, however, depend to a marked degree on the initial condition of the surfaces, the lubricant and the alignment of the specimens. The wearing-in period was more marked with the chill-cast alloys than with the sand-cast ones.

With all alloys except that containing only 0.25 per cent lead, the torque fell to relatively low values after wearing-in. The alloy containing 0.025 per cent lead, while worn-in more rapidly, showed widely varying frictional properties. No appreciable wear of the steel could be detected. Strain lines were observed on the two of the specimens tested under sliding friction and surface flow with the high-lead bronzes.

In the case of wear tests made under dry sliding friction, the temperature rose rapidly and marked surface flow of the metal took place. The tests were erratic and difficult of interpretation, hence in the case of dry friction the investigation was confined to combined rolling and sliding friction.

Film Formation. In addition to changes in the roughness of the surface produced by running, surface films were also developed. These were of two types, *viz.*, a film appearing to be copper oxide, which was most evident on the low-lead alloys, and black film of lead or lead compound found on the high-lead alloys. X-ray analysis failed to disclose their exact nature. The authors ascribe some of the erratic results obtained to film formation. In some cases the films appear to consist of particles torn off from the metal and oxidized. Removal of these particles by copper scrapers reduced the tendency to film formation, hence these were used in all of the wear tests without lubrication.

Effect of Composition. In these tests (combined rolling and sliding friction) the rate of wear increased after a preliminary wearing-in period and assumed a relatively high and constant rate. In the alloys having a copper:tin ratio of 92.5:7.5, increase in lead from 0.25 to 5 per cent increased the wear per unit work and per unit slip, while from 5-15 per cent lead the wear decreased again, and remained practically constant from 15-25 per cent lead.

In the alloys having a copper:lead ratio of 84:16, increase in tin from 0.7-10 per cent resulted in a great increase in wear per unit work

and per unit slip, this being very rapid between 0.7 and 3 per cent tin, but less rapid above this point.

The chill-cast alloys wore much more rapidly than the sand-cast ones, with the exception of the copper-lead alloy containing 0.7 per cent tin, and the copper-tin alloy containing 0.25 per cent lead for which the rates of wear were about the same for the two kinds of castings.

The frictional torque was low at the beginning of each run but soon increased and in many cases approached a constant high value, while in others it reached a maximum and then gradually decreased. In general the average torque increased with decrease in wear per unit work after the wearing-in period.

The low-tin copper-lead alloys and the low-lead copper-tin alloys exhibited surface roughening with ridges and also a flat wheel effect which resulted in heavy pounding. In other cases the surface was not so rough and in some a film was formed. Transitory films which did not affect the rate of wear were also observed with most of the alloys. Smooth surfaces were observed oftener on the sand-cast than on the chill-cast alloys. Very stable films were formed on sand-cast bronzes containing 15 per cent lead. In some cases fragmentation of the metal immediately under the worn surface was observed. Stable films generally decreased the rate of wear while the torque was decreased with both transitory and stable films. The torque was much higher for the low-lead alloys than for those containing 10-25 per cent lead.

Reproducibility of Wear Tests. Specimens from the same casting were run in the Amsler machine by two different observers, the second observer interchanging the steel disk with the bronze specimen. Close checks were obtained except with the low-tin alloy where it was not possible to go beyond the wearing-in period due to flat wheel effect and pounding.

Unlubricated Wear Tests at Elevated Temperatures. Wear tests were also made at 80° C. and 175° C. In the case of bronzes with varying lead content, the curves for the different alloys were similar above 5 per cent lead, but below this lead content the wear rate at atmospheric temperature decreased with lead content while that at elevated temperatures increased. No explanations are given but it is stated that the results were reproducible.

Except in the case of the bronze containing 0.25 per cent lead the chill-castings had a higher rate of wear than the sand-castings, and also wore in more rapidly.

In the case of the bronzes with varying tin content, the increase in rate of wear due to increase in temperature is less in the bronze containing 10 per cent tin than in those containing 2.5 per cent tin or less. The chill-castings wore faster than the sand-castings in every case.

Except in the case of the alloys containing 2.5 per cent or less tin, which developed very rough surfaces, the wear per unit work was high when the average torque was low and *vice versa*. The authors state that a possible explanation of this may be that a soft tough metal would readily deform and give high torque values but the displaced particles would not be broken off, so that the wear would be low, while the reverse might occur with a hard brittle alloy.

The wear of the steels was generally erratic but it was found that on the whole, the wear decreased with increase in lead content of the bronze, there being even an increase in weight with the high-lead bronzes due to deposition of particles from the bronze. With a few exceptions the steels wore faster with the sand-castings than with the chill-castings.

The series of bearing bronzes was subjected to the action of a sand blast and the loss in weight determined. It was found that in every case but one the sand castings were more resistant to sand abrasion than the chill-castings. The rate of wear decreased with increase in tin content and increased with increase in lead content, large weight losses being obtained with the high-lead alloys due to the high specific gravity of the lead particles torn out. The effect of variation in lead then, was in the opposite direction to that occurring when the dry specimens were rubbed against steel, in the Amsler machine.

The mechanical tests will not be described in detail but the conclusions of the authors from the whole investigation will be quoted as follows:

"1. No one of the selected laboratory tests yielded information which was, by itself, adequate for general comparisons. Each of the wear tests and the mechanical tests contributed information of value in developing the characteristics of the different bronzes.

"2. Variations in the chemical composition of the bronzes produced major changes in properties, but within certain ranges variations in chemical composition were much less important than variations in methods of casting.

"3. As a general rule, chill-cast bronzes wore faster and had lower

notch-toughness than the corresponding sand-cast bronzes, but showed better resistance to pounding and higher tensile strength at temperatures between 70° and 600° F. (20° and 315° C.). The few exceptions to this are shown in detail in the report.

"4. In alloys with a practically constant ratio of copper to tin, increase in lead produced a general improvement in wearing properties, but this was more marked between 0.25 and 12 per cent than between 12 and 25 per cent lead. At the same time the resistance to pounding, notch toughness, and tensile strength decreased.

"5. In alloys with a practically constant ratio of copper to lead, increase in tin from 0.7 to around 5 per cent resulted in a marked decrease in the wear produced by rolling and sliding friction without oil and a general improvement in the wearing properties. Further increase in tin from around 5 to 10 per cent did not materially modify the wearing properties but resulted in improved tensile strength and resistance to pounding. There was also an improvement in notch-toughness with an increase in tin to about 7 per cent, representing the proportion above which appreciable amounts of the brittle *alpha-delta* eutectoid appeared. With higher tin a slight decrease was observed in the impact values.

"6. The bronzes with less than about 5 per cent tin did not seem to have the combination of mechanical and wearing properties necessary for good service as bearings. Where wearing properties are of primary importance the high-lead bronzes have distinct advantages over the low-lead bronzes. Likewise the bronzes with around 8 to 10 per cent tin (and 12 to 15 per cent lead) seem better adapted to service where the chief requirements are resistance to pounding and static stresses than bronzes with around 4 to 6 per cent tin.

"7. There is a considerable range of chemical composition within which the variations in mechanical and wearing properties are small. This includes a range from 15 to 25 per cent lead and around 4 to 7 per cent tin. Since the alloys within the entire range have given reasonably good performance in locomotive and journal bearings, there does not seem to be justification for the wide variation in specifications now used by different carriers for parts subjected to similar service. This refers not only to the type compositions but also to the limits of chemical composition for any one type.

"8. It has been shown that reproducible tests can be obtained in the laboratory. The results, when combined with suitable mechanical

tests, gave comparisons which were consistent with some experiences in practical service."

There is a wealth of material in this paper which is well worth the study of anyone interested in bearing bronzes.

14. Three Metal Bronzes. A. M. Blow, *Met. & Chem. Eng.*, 12:461-466 (1914).

The author outlines the properties of Cu-Sn alloys and then considers the effect of additions of Pb, Zn, P, Mn, or Al.

The discussion of the constitution of Cu-Sn is based on the diagram of Heycock and Neville. In the alloys generally used the ratio of Sn:Cu is not over 1:4.

The authors sketch a ternary diagram for the system Cu-Sn-Pb, but state that few points have been determined experimentally. A discussion on the basis of this diagram follows.

Under normal conditions Pb is merely distributed through the mass, the structure of plastic bronzes being the reverse of most bearing metals, *i.e.*, the matrix is harder than the included particles. Experiments of the Pennsylvania Railroad are cited. Further experimentation has shown that the limit of Pb may be raised from 15 to 30 per cent. This, however, is less than the lower limit of the two liquid phase region in the system Cu-Pb, *viz.*, 35 per cent Pb. The limit may, however, be changed by mechanical manipulation.

Segregation may be prevented by the addition of other elements, notably Ni, S, or P. With 1 per cent Ni, 30 per cent Pb may be included even with unskillful handling. The effect of Ni is to extend the alpha solid solution range in the Cu-Sn system. S decreases the possibility of liquation by lowering the upper temperature limit of the two liquid phase regions. S exists as Cu_2S (Allan metal). The addition of P causes formation of hard particles of Cu_3P but allows better castings to be produced.

The author discusses the system Cu-Sn-Zn on the basis of its equilibrium diagram. The structure of Lumen bearing metal (Zn, 85; Sn, 10; Cu, 5) is: primary dendrites of epsilon solid solution (14 per cent Cu) enveloped by beta solid solution, and a matrix containing small streaks of beta and Sn. The structure of Parson's white brass is described. If Cu is over 8 per cent in high tin, or over 14 per cent in high zinc alloys, constituents are formed which are undesirable.

Certain heavy duty bearing metals fall in the class of Muntz metal containing tin. The white metals on the Sn-Zn side of the diagram

are harder than the Pb-Sn-Sb bearing metals and are more adapted to carrying heavy loads.

A discussion of phosphor bronzes is given. The addition of P greatly increases the hardness and resistance to wear, but the tensile properties suffer. P should be used merely as a deoxidiser and therefore its content should be kept low. Pb should be added if the alloy is to be used as bearing metal.

Mn and Al bronzes are discussed.

15. The Aluminium Bronzes. R. Guerin, *La Nature*, 48(2):251-255 (1920). [From *Tech. Rev.*, 8:163 (1921).]

The author gives a résumé of the properties of the Al bronzes. Reference is made to the pioneer work of Sainte-Claire Deville and the recent researches of Guillet, Le Chatelier, de Fleury, et al. He refers also to the researches by Breuil on quenching and annealing at the French Aeronautic Laboratory during the war. Photomicrographs of forgeable bronzes cast by the Durville process, which produces perfectly sound ingots, reveals presence of hard fine grains embedded in a plastic matrix. These alloys have lower friction and greater resistance to wear than the phosphor bronzes. Under loads which would have caused the failure of any anti-friction metal, Al bronze rollers stood service test without apparent wear. This bronze is also an excellent conductor of heat. At 350° C., Cu, 90; Al, 10 had the following properties: Ultimate tensile strength $= 50$ kg/mm^2 (71,000 pounds per sq. in.), elastic limit $= 31$ kg/mm^2 (44,000 pounds per sq. in.), elongation $= 15$ per cent. The elastic limit increases slightly with the temperature.

16. Researches on Special Bronzes. I. Lead Bronzes. F. Giolitti and M. Marantanio, *Gazz. chim. ital.*, 40(1):51-77 (1910).

The authors limit their research to alloys containing less than 25 per cent lead and less than 25 per cent tin, on account of the complex character of the Cu-Sn system and because of the limited means at their disposal. They give an equilibrium diagram of the system Cu-Pb showing the two-liquid phase region to exist from 12-60 per cent Pb. (See, however, Abstract No. 81.) The arrest points and their durations are given, as obtained from the cooling curves of 26 alloys of the system Cu-Sn-Pb. A sketch of the Cu corner of the equilibrium diagram is given. A long discussion of the cooling curves follows.

The Brinell hardness of 30 slowly cooled alloys was determined. These results are given in Table 1 of the original article.

17. New Bearing Bronze. Anonymous, *Iron Trade Rev.*, 54:1009 (1914).

The American Metal Company of Pittsburgh has tested the efficiency of its new alloy, Cu, 65; Pb, 30; Sn, 5, in journal bearings. The metal was treated in crucibles.

In a test on the Baltimore and Ohio Railroad a 22 lb. bearing of this metal on a locomotive tender withstood 51,000 miles of service with only one thirty-second inch wear and with no sign of heating. Other bearings on the same tender were rebabbitted six times during the same period.

For mill purposes, bearings of this alloy may be hardened. At the Jones and Laughlin Co.'s mills two 75 lb. brasses of this alloy were installed under a 108 in. plate mill, where they carried a load of at least 10,000 lbs. They gave continuous service for four weeks. No lubrication was possible but graphite in the lead acted as a lubricant.

18. A Ternary Alloy Bearing Metal. Anonymous, *J. Soc. Automotive Eng.*, 15:393-394 (1924).

The Bureau of Aeronautics, United States Navy, has brought to light a little known bearing metal and is adopting it for use in all aircraft engines. The composition is: Pb, 21-25; Sn, 4.5-6.5; Cu, balance. The specification requirements are:

For pigs: Ultimate tensile strength = 20,000 pounds per sq. in.; elastic limit in compression = 12,000 pounds per sq. in.; elongation (in tensile test) = 15 per cent.

For castings: Ultimate tensile strength = 20,000 pounds per sq. in.; elastic limit in compression = 12,000 pounds per sq. in.; elongation (in tensile test) = 10 per cent.

Fracture must show uniform composition without segregation of lead, it must be possible to heat metal to 1200° F. (650° C.) without sweating out of lead. (Gradually bring sample up to this temperature and scrape at intervals with a knife blade.)

Founding: keep core soft, sand dry, melt covered with charcoal until the solution point is reached. Stir with a graphite (preferable) or nichrome rod, never an iron one.

The alloy machines comparatively easily. There is no change of properties on remelting. For expansion, allow 0.005 to 0.007 inch

clearance on a 3-inch diameter. Temporary failure of the lubricant has little effect.

The alloy is heavier than other bearing metals but this disadvantage is outweighed by superior wearing qualities.

It has been used for: auto main bearings, valve stem bushings, locomotive connecting and main road bearings, loose pulley bushings, armature bearings in street railroad motors. In a test of the Wright-Navy aircraft engine for 572 hours at full throttle, connecting rod bearings of this metal were used and needed no repairs or adjustment after the test.

19. Patents on Bearing Metals. A. Allan, Jr., *Metal Ind. (N. Y.),* 7:243-244 (1909).

Allan believes that Clamer claims patents on alloys containing not over 7 per cent Sn, not less than 20 per cent Pb and the balance Cu. The granting of this patent seems absurd as the art of producing Cu-base bearing alloys containing under 7 per cent Sn and over 20 per cent Pb was pursued long before the time of Clamer's patent.

In 1879 A. Allan, Sr., invented a secret process for alloying Cu and Pb in any proportion, with or without the use of Sn, such that a perfectly homogeneous mixture resulted. These alloys, however, were not placed on the market until 1891, when they appeared under the name of Allan Red Metals. Large quantities were sold prior to 1900. Photographs are given of some large bearings made of Allan metal.

If Sn is added it is to harden the alloy, not to prevent the segregation of Pb. Allan, Sr., learned from experience that Sn, Ni or other metals were injurious to the anti-frictional and wearing qualities of Cu-Pb, making the alloy hard without raising the melting point. Sn was especially undesirable because of its adhesive qualities.

20. The Patent Situation in the U. S. Part of a paper given by G. H. Clamer before the American Foundry Association, May 19, 1909 *Metal Ind. (N. Y.),* 7:244-246 (1909).

In 1900 a patent was granted to G. H. Clamer and J. G. Hendrickson for a series of Cu-Pb-Sn alloys having over 20 per cent Pb and under 7 per cent Sn.

The history of the development of bearing bronzes follows. In the early days of railroading, Cu-Sn alloys containing as much even as 15 to 20 per cent Sn (bell metals) were used as bearing metals, the supposition being that the harder the metal the less the wear. It was

well known that the harder metals had lower coefficients of friction. As these high tin alloys were not yielding enough the tin content was lowered to 10 per cent, the standard for many years. About 1870 Hopkins was granted a patent for lining bearings with a soft metal, the object being to make the bearing self-fitting. The success of this idea was phenomenal.

During this period Alexander Dick in England invented the alloy: Cu, 80; Sn, 10; Pb, 10, which became largely used in England but not in the United States. About 1 per cent phosphorus was also added (Standard Phosphor Bronze).

In 1892 Dudley, chemist for the Pennsylvania Railroad, conducted an elaborate series of tests which showed that the rate of wear and the tendency to heating diminished with the Pb content and increased with the Sn content. He tried making high lead alloys, but failed to obtain alloys in which the Pb did not segregate if the Pb content was higher than that in his Ex. B Metal, *viz.*, Cu, 77; Pb, 15; Sn, 8. This failure was probably due to impurities, practically all Dudley's alloys containing P. The presence of P lengthens the time of solidification greatly, which is just the condition to be avoided.

Clamer and Hendrickson's patents (1900) covered processes of making Pb bronzes without segregation of the Pb.

The first patent covered the use of Ni, the effect of Ni being to produce a quick solidifying matrix, which would hold the Pb evenly distributed. (The Pb is only mechanically held.) Ni gave the best results of the high melting point metals.

Investigation showed, however, that a quick solidifying matrix could be obtained without the use of a fourth element and by ordinary foundry methods. The point was to limit the Sn in proportion to the Cu so that all the Sn was in solid solution in the Cu (alpha phase). This meant that the ratio Sn:Cu must be less than 9:91. The second patent covered alloys with not less than 20 per cent Pb, not more than 9 per cent Sn, the balance being Cu.

Suit for infringement was brought against the Brady Brass Company and three years thereafter, a decision favorable to the plaintiff was handed down by Judge Archbold on July 3, 1907.

An appeal was taken to the United States Circuit Court of Appeals, which reversed the decision of Judge Archbold, finding that the claims of the patent covered only a product and not a process, and that the alloy, as covered by the claims, differed from other known

Cu-Pb-Sn alloys in degree only and, therefore, was not patentable. The patent was therefore declared invalid.

The United States Supreme Court on appeal denied *a certiorari*, and an appeal was made to the United States Commissioner of Patents for a reissue of the patents. After thrashing out the matter for four years, six errors had become apparent in the patent specifications. In view of this, and the provisions of patent law (see patent section), a reissue patent was granted, thus sustaining the opinion of Judge Archbold. The reissue patent is the same as an entirely new patent and is in no way affected by the decision of the United States Circuit Court of Appeals.

21. **Patent Controversy Over Bearing Metals.** Editorial Note, *Metal Ind. (N. Y.)*, 7:243 (1909).

Considerable time and money have been spent in litigation over the validity of a patent assigned to the Ajax Metal Company of Philadelphia, covering the production of a certain Cu-Sn-Pb bearing metal known as Plastic Bronze. The Ajax Metal Company brought suit against the Brady Brass Company of Jersey City, N. J., for infringement of this patent. Claims for and against the validity of this patent are given in the following abstracts.

22. **The Patent Controversy Over Bearing Metals.** Ch. M. Reubens (Criticism and Comment), *Metal Ind. (N. Y.)*, 7:299 (1909).

The writer denies that the art of alloying Cu and Pb in any proportion was invented by Allan, Sr., in 1876.

He calls attention to a book by Johann Tenner, published in 1860, "Handbuch der Metall Legirungen", which gives a method for making a Cu-Pb alloy. Tenner mentions an alloy previously patented in France which contained 20-25 per cent Pb, although it was not used as a bearing metal. Guettier in his "Guide Pratique des Alliages", 1865, describes the properties of the system Cu-Pb.

23. **Regarding Patents on Bearing Metals.** Ch. Vickers (Criticism and Comment), *Metal Ind. (N. Y.)*, 7:337 (1909).

Allan is right when he says tin is unnecessary to hold Cu and Pb together. For high strength bearings, however, Sn is necessary. Other metals can be used as hardeners besides Sn, but casting of the alloys is more difficult.

One alloy which gave excellent service was Cu, 69.2; Pb, 26.1; Mn, 1.7; Sn, 1.5; Fe, 1.7.

The art of alloying Cu and Pb is not a secret as Allan claims but is very easily accomplished. The difficulty seems to be in being permitted to do it.

24. **Bearing Metals with Twenty Per Cent Lead. J. J. Canning** (Criticism and Comment), *Metal Ind. (N. Y.)*, 7:377 (1909).

The writer says that bearing metals with 20 per cent or more Pb are nothing new. He used tons of metal containing 20-22 per cent Pb made by the Damascus Bronze Company, while a foreman at the Cooke Works, now the American Locomotive Company.

25. **The Patent Controversy Over Bearing Metals. A New Development in the Situation. G. H. Clamer,** *Metal Ind. (N. Y.)*, 7:284-286 (1909).

In reply to Allan's criticism that his paper "The Patent Situation in the United States" does not fit its title, but is rather the epitome of a personal situation, Clamer states that legal situations are created by decisions of the courts, and the decisions handed down by the courts in the plastic bronze case are the only decisions affecting the validity of a United States patent for alloys. This case has created the situation as it stands today.

The author lists the difference between Plastic Bronze and Allan Red Metal as follows:

1. Plastic Bronze is a Cu-Pb-Sn alloy having Sn less than 9/91 of the Cu, and the Pb more than 20 per cent of the whole.

1. Allan Red Metal is a Cu-Pb alloy without Sn.

2. Plastic Bronze is strong enough for heavy duty bearings, its strength being due to Sn.

2. Allan Red Metal is not strong enough for car bearings, etc., in fact is weaker than Pb base babbitt.

3. Structure of Plastic Bronze is a matrix of Cu-Sn solid solution holding the Pb in a purely mechanical manner.

3. Allan Red Metal is merely a mechanical mixture of Cu and Pb. As it contains about 50 per cent Pb the walls of the matrix must be thin.

4. The matrix of Plastic Bronzes solidifies from 1940 to 1760° F. and the Pb is held in a liquid state in the matrix until it freezes at 622° F. (Cu, 65; Pb, 30; Sn, 5).

4. Clamer claims that the Pb has no effect on the freezing point of Cu, viz., 1976° F., and the Cu none on that of the Pb.

Analysis of Allan Red Metal showed sulfur present in greater amount than could be accounted for by use of the most impure Cu or Pb. It is therefore part of the secret Allan process. Photomicrographs are given showing that Pb can be held mechanically just as well without sulfur.

26. The Patent Controversy Over Bearing Metals. A. Allan, Jr.,
   Metal Ind. (N. Y.), 7:321-323 (1909).

Allan states that between 1891 and 1898 with the exception of Allan metals not a single Cu-Pb alloy, with or without Sn, was on the market which would hold over 15 per cent Pb without the use of Ni.

He states that Clamer's statements are contradictory. In one place he says that he makes no claims to an alloy without a hardening constituent, and in another place he says that by the process he and Hendrickson invented they are enabled to alloy Cu and Pb in any proportion with or without Sn. "Do not Clamer's statements prove that the art is based on the production of an alloy which will hold more Pb than is possible without the use of Ni, an art invented by Allan, Sr., in 1876?" Allan states that Pb, not Sn, is the critical element. He says Clamer must prove his statement that Sn when present in too great amount will cause segregation of Pb, if there is over 20 per cent of the latter.

Allan does not recognize Clamer's photomicrographs as ones of his product. Pb does lower the melting point of Cu, in spite of Clamer's statement to the contrary. He has no retractions to make of statements in Allan Bulletin No. 1.

27. The Patent Controversy Over Bearing Metals. G. H. Clamer,
   Metal Ind. (N. Y.), 7:407-408 (1909).

Clamer does not retract any of his previous claims, and sums up his point of view thus:

(1) Plastic Bronze and Allan's metal or other similar alloys are not in the same class either from a service point of view in their properties or constitution.

(2) Allan's metal does not have a melting point of 1500° F. (816° C.) as claimed by Allan, but will go to pieces if heated above the melting point of lead, 621° F. (327° C.). Clamer gives an equilibrium diagram from the 4th Alloys Research Report of the British Institute of Mechanical Engineering showing the small mutual solubility of lead and copper. Clamer misinterprets the diagram,

stating that the copper being almost free from lead starts to solidify at the melting point of the pure metal, 1981° F. (1082° C.) and becomes all solid at 1750° F. (954° C.), but the lead does not solidify until the temperature is lowered to 627° F. (332° C.).

(3) Cu-Pb is not homogeneous (as regards micro-structure).

(4) There is no special process necessary to produce Cu-Pb free from segregation, except that the metal should be poured at as low a temperature as possible.

(5) The critical composition Cu, 91; Sn, 9 is a well established fact, *cf.* Heycock and Neville (210).

(6) We have taken advantage of this fact to obtain a Cu-Pb alloy of sufficient strength, not to hold the Pb.

(7) Allan, Sr., did not invent the series of alloys to which plastic bronze belongs. Cu, 80; Pb, 20 was made long ago, and known as pot metal. The Allan process appears to depend on the use of S and Bi. No secret process is necessary for the manufacture of plastic bronze.

28. The Patent Controversy Over Bearing Metals. (5th Paper.)
A. Allan, Jr., *Metal Ind. (N. Y.),* 8:67-72 (1910).

The author gives photomicrographs and a table of mechanical properties of three Allan Red Metals and one Plastic Bronze as follows:

Mechanical Properties of Allan Red Metals and a Plastic Bronze.

Alloy	Elastic Limit in Compression	Compressive Strength
	Pounds per Square Inch	
Plastic Bronze	15,000	64,000
Cu 58.5, Pb 35, Sn 6.5..............	15,000	57,000
62.5 30 7.5..............	19,500	76,400
67 24 9	31,000	80,800
70 20 10	23,000	91,900

Allan claims that the ratio of 91 Cu to 9 Sn is not critical and gives some photomicrographs to prove his point, which are not very clear, however. He gives a freezing point curve of Allan No. 1 Red Metal taken by Sauveur and Boylston, which shows heat effects at 970° C. and 390° C., the upper limit not being at 1060° C., as claimed by Clamer.

Allan claims that castings of his alloys cannot be produced in any size without sweating lead, if ordinary foundry methods are used. In his process continual stirring is unnecessary, only skimming is needed to hold back any dirt. He denies that Cu-Pb with over 25 per cent Pb can be cast without Pb sweat except by his process.

Allan reproduces Heycock and Neville's equilibrium diagram of the system Cu-Sn, showing that the temperature range of freezing intervals is greater at 9 per cent Sn than at 15 per cent Sn. (He erroneously assumes that the time of freezing is also greater.)

Allan claims that Bi plays no part in his process, although S does. Allan's alloys show presence of the Cu_4Sn eutectoid and are still merchantable alloys, disproving 9 per cent Sn being a critical point.

29. The Patent Controversy Over Bearing Metals. (6th Paper.) G. H. Clamer, *Metal Ind. (N. Y.)*, 8:208-211 (1910).

Clamer is familiar with the fact that Cu, Sn and Pb may be mixed in the proportions given by Allan, but claims it can be done by ordinary foundry methods. The photomicrographs given by Allan have no bearing on segregation. He challenges Allan to make Cu, 58; Sn, 10; Pb, 32 or Cu, 63; Sn, 9.5; Pb, 27.5 by his process. He concedes that they cannot be made by ordinary foundry methods. He notices that Allan lowers his Pb content with increase in Sn, a fact which Clamer had discovered necessary. Apparently the introduction of Sn into Allan Red Metals came after Clamer's discovery. In the older Allan pamphlets it was stated that the presence of Sn was very undesirable.

Clamer quotes Sauveur's testimony at the patent hearing. The latter based his argument on Heycock and Neville's equilibrium diagram and showed that Cu, 85; Sn, 15 really took about four times as long to solidify as Cu, 95; Sn, 5. Below 9 per cent Sn only one kind of solid solution exists and above 9 per cent Sn there are two, one of which on cooling changes to Cu_4Sn, the constituent which increases the hardness and decreases the plasticity.

Clamer denies Allan's claim that his process is necessary to produce alloys containing over 25 per cent Pb without Pb sweat occurring. To disprove this he has sent to *The Metal Industry* a sample of such an alloy produced by ordinary foundry methods. Such are also made by several railroads. Sauveur also testified that he made up Cu, 65; Pb, 30; Sn, 5 and Cu, 73; Pb, 20; Sn, 7, which cast into bearings showed neither segregation nor Pb sweat.

30. The Patent Controversy Over Bearing Metals. (7th Paper.) A. Allan, Jr., *Metal Ind. (N. Y.)*, 8:289-291 (1910).

Allan asks why Clamer applied for a patent based on a critical relation between the Cu and Sn contents when he knew that it was possible to make alloys of the compositions given by himself. In a

paper before the Franklin Institute Clamer admitted that he was unable to produce good castings if the Sn content was too high, but that a certain amount of Sn was necessary to prevent segregation.

Allan denies that there is an abrupt change in the rate of cooling at 9 per cent Sn, but now admits that the freezing interval is longest at the eutectic composition, 22 per cent Sn. The equilibrium diagram, however, is valid only for very slowly cooled alloys, and not for those produced in practice. The limit of solid solubility is less as the rate of cooling increases, therefore the critical point varies with the rate of cooling. The freezing range is also altered by the presence of Pb. He challenges Clamer to make bearing metals of certain compositions which are made by the Allan process. (See next abstract.)

The Metal Industry had analyses made of the two bearings made by Allan in answer to Clamer's challenge and the compositions were found to be that proposed by Clamer.

31. The Patent Controversy Over Bearing Metals. (8th Paper.)
    G. H. Clamer, *Metal Ind. (N. Y.),* 9:114-118 (1911).

Clamer examined the bearings sent in by Allan to the office of *The Metal Industry* and finds that though in external appearance they are good bearings, without Pb sweat, their backs are somewhat porous and scruffy, no doubt due to the use of sulfur. From the analysis, which showed 0.88 to 1 per cent S, it is safe to assume that all this was in combination with the Cu as Cu_2S, a brittle, friable substance of lower density than the alloy. The appearance of the bearing is due to this sulfide floating to the surface.

Allan has produced alloys so far outside the Clamer patent that so far as the ratio of Sn to Cu is concerned, he has proved that S has influenced the retention of Pb in such alloys. He claims that such alloys can be produced by ordinary foundry practice if S is added, by plunging a stick of sulfur under the surface of the molten metal. Additions of S are unnecessary within the limits given in the patent.

Allan's claims to the contrary, the amount of Pb which may be held is limited by the amount of Sn. Clamer gives a curve showing this limiting amount. If impurities are present, the allowable amount of Sn is less.

Clamer sends to the office of *The Metal Industry,* bearings of Cu, 67; Pb, 24; Sn, 9; . . . Cu, 70; Pb, 20; Sn, 10; . . . Cu, 65; Pb, 30; Sn, 5; . . . Cu, 58.5; Pb, 35; Sn, 6.5; . . . Cu, 62.5; Pb, 30; Sn, 7.5. The two latter he was unable to make without the use of S, and admits

now that he was unable to make such alloys before. He states that as the last named segregates with 7.5 per cent Sn and not with 5 per cent, it is conclusively shown that Sn beyond a certain amount promotes Pb segregation. He supports this by photos of bearings made with and without S. Bearings made of the first two alloys did not sweat or segregate without S. He points out that the temperature interval is not proportional to the time interval of freezing. He claims that the critical point is little influenced by the presence of Pb, but admits it may be shifted by the rate of cooling. He gives Sauveur and Boylston's cooling curve for Cu, 65; Pb, 30; Sn, 5, and shows that the heat effects are at approximately the same temperatures as for the above ratio of Sn to Cu, as shown in Heycock and Neville's equilibrium diagram of Cu-Sn.

Clamer says that Allan has not proven his claims in regard to the effect of Sn on segregation of Pb, as he has prevented segregation in a different manner, *i.e.*, by the use of S.

32. The Patent Controversy Over Bearing Metals. (9th Paper.) A. Allan, Jr., *Metal Ind. (N. Y.)*, 9:155 (1911).

Allan still maintains that the art of alloying Cu with Pb with or without the use of Sn was invented by his father. He cannot produce by ordinary foundry methods or has he seen so produced by others merchantable castings of Cu-Pb or Cu-Pb-Sn alloys, containing over 25 per cent Pb. However, if anyone knows how to produce these, his opinion is that he may do so regardless of the Clamer patents, and with or without the use of S.

If ordinary foundry practice can overcome the difficulty of Pb segregation it never existed to be overcome. Clamer concedes that the Allan process controls the Pb when Sn:Cu is greater than 9:91, he must then admit that it does so when the ratio is less than this.

Clamer acknowledges by his diagram that he cannot produce some alloys which are within the limits of his patent claims. Allan thinks that Clamer should produce evidence to show that he can produce all the alloys claimed by him by ordinary foundry methods. Allan suggests that Clamer send to the office of *The Metal Industry* 100 lbs. of Cu, 55; Pb, 40; Sn, 5 made by ordinary foundry practice. If analysis shows the castings to be of this composition, castings shall be made of these under *The Metal Industry's* supervision. If these show no Pb sweat or segregation he will concede Clamer's point and stand the cost of the investigation.

33. The Patent Controversy Over Bearing Metals. (10th Paper.)
    G. H. Clamer, *Metal Ind. (N. Y.)*, 9:206 (1911).

Clamer states that Allan metal, previous to the advent of Plastic Bronze on the market, was a pure Cu-Pb alloy, and that all the Allan literature decried the use of Sn and stated that Allan Red Metal contained no Sn whatsoever. Clamer seems to think that a ternary alloy will necessarily have different properties from any of the binary ones composing it, though it is true, as pointed out by the courts, that there is no analogy between Cu-Pb and Cu-Pb-Sn. Clamer casts aspersions on the benefits of Allan's 18 years' foundry experience, stating that Dr. Sauveur, with no foundry experience, had made castings of Cu, 65; Pb, 30; Sn, 5 by ordinary foundry methods. The fact that Allan has not seen castings of Cu-Pb-Sn containing over 20 per cent Pb does not affect the fact that millions of pounds of such metal have been made.

Clamer states that Allan has not read the patent claims carefully enough. It is stated therein that Pb may be present in any amount above the lower limit though it must remain within the requirements of a bearing. Clamer admits that Cu, 55; Pb, 40; Sn, 5 cannot be made by ordinary foundry methods, but it is too soft for a solid bearing. He also states that his diagram fully supports the claim of the patent. Allan's is not within its meaning.

34. The Patent Controversy Over Bearing Metals. (11th Paper.)
    A. Allan, Jr., *Metal Ind. (N. Y.)*, 9:295-297 (1911).

Allan claims that his diagram is within the claims of Reissue Patent 12,880, and that Clamer has admitted he cannot make some alloys covered by the claims.

Clamer is correct regarding the absence of Sn from Allan Red Antifriction Metal in which it is very deleterious. The Allan Bronzes, however, are Cu-Pb-Sn alloys. The proportion of Sn added is dependent on the service requirements.

If Clamer's patent claims are valid, why should he not be able to make Cu, 59.5; Pb, 35; Sn, 5.5 or Cu, 55; Pb, 40; Sn, 5. Allan denies that the latter alloy is too weak for solid bearings since its elastic limit is 14,000 pounds per sq. in. and its compressive strength is 45,400 pounds per sq. in. It is strong enough for railroad bearings.

Allan contradicts Clamer's statement that the freezing point of Cu is not lowered by Pb. Roberts-Austen found that 35 per cent Pb lowered the freezing point by 135° C., while other measurements have

shown that the addition of 30 per cent Pb to a 91:9 bronze lowered the freezing point by 125° C.

In regard to the millions of pounds of alloys containing over 25 per cent Pb, can Clamer prove that their analyses are complete, as few chemists would determine the S content. Allan states that samples of Plastic Bronze purchased in the open market gave analyses showing as much S as Clamer stated he found in Allan Red Metal. S is not an impurity of market Cu or Pb, nor could it have been derived from the coke used in melting. It, therefore, must have been introduced intentionally. In Clamer's paper before the American Brass Founders' Association in 1909, he says: "This with a small per cent of S which is of no materiality is the combination made use of by the defendant (Brady Brass Company), who thus admittedly infringe if the patent is valid". Again in 1909 he said, "I can say positively that Pb may be held in mechanical mixture with Cu without S as well as with it".

The use of S to prevent Pb segregation is part of the Allan process but not all of it. Clamer's alloys made by ordinary foundry practice with the use of S are far within the limits of those possible by using the entire process. He challenges Clamer to send to the office of *The Metal Industry* samples of Cu, 50; Pb, 50; Cu, 65; Pb, 30; Sn, 5 and Cu, 67; Pb, 24; Sn, 9 made by ordinary foundry practice. If the analyses are found to be as above, and the alloys can be cast into merchantable castings, showing no Pb sweat or segregation, Allan will stand the cost of the investigation.

35. Patent Controversy Over Bearing Metals. (13th Paper.) G. H. Clamer, *Metal Ind. (N. Y.)*, 9:418-420 (1911).

Clamer restates his views regarding effect of sulfur on lead bronzes. He holds it is not necessary for the production of alloys under Reissue Patent 12,880. The field outside this patent is open to all.

He says that the Allan copper-lead alloys first appeared on the market about 1891, the Ajax plastic bronzes in 1900, and it was not until after his paper before the American Foundrymen's Association in 1909, that he ever heard of any Allan copper-tin-lead alloys.

Clamer denies that there has been any intentional addition of sulfur in the manufacture of Ajax plastic bronzes. He sends to the office of *The Metal Industry* for analysis and casting, test ingots of Cu, 50; Pb, 50 . . . Cu, 65; Pb, 30; Sn, 5 . . . Cu, 67; Pb, 24; Sn, 9 without sulfur and one of Cu, 50; Pb, 50 containing sulfur. This latter shows better mixture than the one without sulfur.

36. Patent Controversy Over Bearing Metals. (14th Paper.) Editor, *Metal Industry (N. Y.)*, 10: 167 (1912).

All of Clamer's alloys (see Abstract 35) except the one containing sulfur were analyzed, and only the Cu, 50; Pb, 50 showed marked lead segregation. They were all satisfactorily close to the compositions claimed. A cylinder 8 in. long by 5 in. diameter was cast of each alloy. None of these showed any visible segregation, although some was detected by chemical analysis, as follows:

		Copper	Tin	Lead
Cu, 67; Sn, 9; Pb, 24	Top	62.90	8.51	28.40
	Bottom	66.26	8.82	24.59
Cu, 65; Sn, 5; Pb, 30	Top	66.70	4.88	28.31
	Bottom	65.92	5.04	28.92

Clamer's statement that less segregation is present with the alloy having less tin, is confirmed. Clamer suggested having a commercial foundry make castings of Cu, 65; Sn, 5; Pb, 30 and Cu, 60; Sn, 10; Pb, 30. He predicted that the first alloy would not show lead sweat and the second one would. This has been done, with the result predicted by Clamer.

37. Ulcoloy. Anonymous, *Met. & Chem.*, 13:378 (1915).

A new copper-lead alloy is made by the United Lead Company by a patented process which holds the copper uniformly distributed throughout the mass until it cools and hardens. Its chief applications are as a bearing metal and as metallic packing. It is acid-resisting.

38. Investigations on Bearing Metals. (II. Red Brass.)* E. Heyn and O. Bauer, *Stahl Eisen*, 31:1416-1422 (1911).

The authors investigated a red brass, nominally of the composition specified by the Prussian Railroad Administration, *viz.*, Cu, 84; Sn, 15; Zn, 1. Their Zn content, however, was too low. This alloy apparently suffered little change in composition even after five remeltings. Microscopical examination showed, however, that oxidation of tin took place, but as the oxide was not removed in remelting, the fact was not apparent from the chemical analysis.

A cooling curve of the alloy is given. The alloy in the slowly cooled state consists of primary crystals of *"alpha"* and an *"alpha"*-plus-*"delta"* eutectoid. As the transformations require some time, high temperature forms may be retained by quenching.

* Part I is abstract No. 42.

By quenching from above 782° C., the transformation *"alpha"*-plus-liquid to *"alpha"*-plus-*"beta"* at this temperature is suppressed, and a much harder product results. Thus, quenching from 900° C. the ball hardness was 97, while on quenching from 700° C. it was only 63.

The density of chill castings runs from 0.2-0.8 per cent higher than that of sand castings. Twelve photomicrographs are given of different conditions of the alloy. The ball hardness of the chill cast alloy was about twice that of the sand cast, and in the impact compression test the ratio of compression to energy absorbed was less for the chill cast alloy. In this latter test, cracks appeared in both alloys at about the same deformation. The yield point in compression was higher for the chill cast alloy.

A bearing cast of metal which had been remelted five times had numerous pores under the skin, and microscopical examination of these showed many gray threads, which according to a previous investigation were tin oxide. Metal remelted only once showed these threads but in much smaller quantity. The hardness of the once remelted metal was slightly greater than that of the five times remelted one; while the tensile strength of the former was 21,000 pounds per sq. in., and that of the latter 18,000 pounds per sq. in. Compressive strength and impact compressive strength were little affected by remelting.

A figure is given, showing the effect on the arrest points, of addition of arsenic up to 1.5 per cent. There is no difference in the melting and pouring due to the addition of arsenic. There is no difference in the microstructure, due to arsenic, except that the sand castings showed many threads of oxide near the pores. Arsenic for the most part causes increase in the ball-hardness. The effect of arsenic on chill castings is to lower the tensile strength and elongation and to raise the yield point. The effect of arsenic on the tensile properties of sand castings is not marked. Arsenical sand castings cracked at the first blow in the impact compression test, but the chill castings withstood a considerable number of blows. In this test lower deformations were obtained if more than 0.65 per cent arsenic was present.

39. The Physical Properties of Red Brass. Anonymous (Signed ev.), *Z. ges Giessereipraxis, Das Metall*, 1927, pp. 141-142.

Red brasses are of great importance as bearing metals and in the construction of parts for rolling stock, steam fittings, etc., and quite definite physical properties are demanded of them. The Reichsbahn

(German National Railroad) uses 100 metric tons per month of these alloys. In view of the difficulties foundries have experienced with them, the Reichsbahn Gesellschaft has built an experimental foundry for carrying on systematic experiments on the porosity and physical properties of bronze and red brass. The causes of porosity will be sought for with especial thoroughness and also the causes for the great variation in these alloys.

When the war ended, it was believed that a single alloy would suffice for all purposes, namely, "Einheits" red brass of the composition Cu, 85; Sn, 9; Zn, 6. The difficulty with this alloy was that it had no definite freezing point but a freezing range between 1000° and 750° C. Consequently in casting thick sections, temperature differences occurred between the inside and the outside, resulting in segregation. Segregation must be held responsible for the so-called sponginess. Dry molds and slow cooling are especially favorable to segregation. In view of the wide freezing range of red brass and its tendency to segregate, the correct design of castings is very important. They must be so designed that the heat given up by thick sections retards the cooling of thin ones, and prevents them from solidifying too much before the thick ones.

Green-sand castings have much better physical properties than dry-sand ones. Chill castings almost never exhibit sponginess if the sections are not too large. Steam is generated in green sand containing 8-12 per cent water, which rapidly removes the heat from the casting. The cohesiveness of the molding sand is also of importance. In the experimental foundry of the Reichsbahn, a new sand testing method has been evolved which allows the permeability of molding sand to be easily and correctly determined.

Applications of Some Red Brasses.

Name	Composition Per Cent				Applications
	Cu	Sn	Zn	Pb	
Red Brass—I	85	11	4	..	Bearings, etc.
" " —II	85	9	6	..	Valves, slides, cocks.
" " —III	91	5	4	..	Pipe flanges and parts difficult to solder.
Red Machinery Brass—I	82	10	7	1	Machinery castings.
" " " —II	85	5	8	2	Machinery castings.
Lead Bronze—I	86	10	..	4	Dynamo bearings, connecting rod bearings.
" " —II	77	8	..	15	Heavy-duty bearings.
Cast Bronze—I	79	20	..	..	Car-journal bearings.
" " —II	85	14	..	..	Heavy-duty bearings.
" " —III	89	10	..	..	Worm-wheels and pump cylinders.

The "Einheits" red brass is not used so much now as formerly, for it was not found to be suitable for all purposes, as originally supposed. The applications of some red brasses are given in the table on the opposite page.

The mechanical properties of some red brasses are given in the table below.

Mechanical Properties of Some Red Brasses.

Composition —Per Cent—			Tensile Strength Pounds per	Elon- gation Per	Cold Bend Test	Applications
Cu	Sn	Zn	Square Inch	Cent	Degrees	
83	12	15	25,600	3	10	Small bearings, not lined with white metal.
85	11	4	25,600	4	20	Large unlined bearings.
86	8	6	28,500	15	45	Thick-walled castings.
86	10	4	28,500	10	30	Valves, slides, cocks, etc.
87	8.7	4.3	25,600	15	45	Machine parts and bearings lined with white metal.
88	11	1	28,500	10	20	Large bearings, castings, etc.
91	7	2	28,500	20	45	Pipe flanges and other parts which must be hard sold-
91	5	4	28,500	20	45	ered.

Chemical analysis is not always decisive as to whether a red brass is good or bad. An idea of the quality, however, may be obtained from the Reichsbahn Gesellschaft test, in which a small specimen is tested for porosity under a hydraulic pressure of 20 atmospheres.

One of the objects of the investigation at the Reichsbahn experimental foundry was to discover any correlation between the chemical composition and result of the porosity test. It was established that the ratio of tin to lead in the alloy increased systematically as the casting became poorer in quality. A whole series of tests showed that "Einheits" red brass was poor if the ratio of tin to lead was less than 3. These facts may form a starting point for further investigations. The relation between chemical composition and segregation has as yet been little investigated. A single constituent or an impurity may affect the quality of the material adversely. Segregation is a cause of poor mechanical properties. The hardness of red brass containing 5 per cent tin is much less variable than that of "Einheits" red brass. These results of laboratory experiments have been confirmed by experience in manufacturing plants.

40. **Babbitt Metal and Its Manufacture.** E. S. Sperry, *Brass World*, 2:75-83 (1906).

The manufacture of babbitt metal has undergone great changes in the last 25 years due to the replacement of some of the more ex-

pensive tin base metals, by alloys containing antimonial lead, which has become available at a reasonable price. The author states that probably more than 97 per cent of babbitt is lead base.

The author traces the history of bearing metals. Bronze or brass was used for good bearings up to the time of Isaac Babbitt (1839). Babbitt metal (tin base) was used for many years, until the advent of antimonial lead. This was sold for less than pure lead, in spite of the fact that antimony cost more than two times as much as lead. The reason for this was that it was the "refuse" of certain silver refineries.

The author classifies babbitts into: (1) Tin-base genuine babbitt; (2) lead-base anti-friction metals; (3) zinc-base white brasses. The addition of bismuth would be of great advantage, if it were cheaper.

(1) *Genuine Babbitt.* Pb may be added to this up to 5-10 per cent without injury. With only 5 per cent Pb the appearance of the alloy is not much changed, the top of the bar still showing the yellow color of tin oxide. Sb does not harden Sn as rapidly as Cu. The following compositions are given: Hard genuine babbitt: Sn, 88; Sb, 4; Cu, 8. Standard genuine babbitt: Sn, 90; Sb, 7; Cu, 3. The latter may have 6 per cent Sn and 1 per cent Sb replaced by 7 per cent of 20 per cent Pb-Sb.

Ni has been recommended as an addition to babbitt, but even 1 per cent will make the metal pour sluggishly. The various Ni babbitts on the market contain about 0.5 per cent Ni. No advantage results from its use.

Zn is injurious. Babbitts containing it are sluggish and have much dross included. White brass is a drossy metal.

Al is used, up to a fraction of 1 per cent, but has no effect except the objectionable one of removing the yellow color from the top of the bar.

The use of P also has this objection, but it is of value sometimes when the metal becomes thick in the kettle. A little added then will make the alloy more fluid.

Mn and Fe have about the same action as Ni.

Mg has been used to a slight extent, but its action is like that of Zn.

In making babbitt, oxidation of the Cu should be avoided by melting this in a covered graphite crucible. The Sb is added to the molten copper and the mixture then poured into the molten tin.

(2) *Anti-friction Metals.* This name was due to the early boosters of antimonial lead. This alloy is a by-product of the silver refineries and sells slightly above pure lead.

It is doubtful if addition of 5 per cent Sn will improve the anti-frictional properties. However, it gives the metal a brighter appearance, and a glistening and coarser fracture.

No. 4 hardware babbitt contains 3 parts of 20 per cent antimonial lead to 1 part of soft lead. New pig lead should be used in making this alloy as scrap does not produce so clean a metal. Standard anti-friction metal is: Pb, 80; Sb, 15; Sn, 5.

The author gives a description of the equipment required. He prefers iron molds for babbitt, although brass molds should be used if a smooth surfaced bar is desired.

41. Metals in Bearings—Anti-frictional Properties of Lead. S. K. Patterson, *Metal Ind. (N. Y.)*, 7:20-21 (1909).

Requisites of a bearing metal are strength and non-brittleness. The coefficient of expansion is a factor where the temperature changes are large, on account of the binding which may result. One should also watch for a change of properties with a rising temperature.

According to Professor Thurston the value of soft white alloys lies in their property of readily reforming a smooth surface after any local impairment. Flaws are readily healed by the soft alloy flowing into them. The coefficient of friction varies in inverse ratio to the compressive strength. The alloys best for high speeds are not so desirable for heavy loads. Bearings have recently been introduced having an iron or steel grid filled with a much softer bearing metal than could ordinarily be used, or even with graphite.

White alloys have a fairly high electrical conductivity and may be used for electrical machinery bearings. Alloys containing sodium are interesting, in that the oxidation products of sodium combined with oil, produce a soap which acts as a lubricant. Tin increases the resistance to wear but is expensive. Lead decreases the friction.

42. Investigations on Bearing Metals—Antimony-Lead-Tin Alloys. O. Bauer, *Stahl Eisen*, 35 (I): 445-450, 553-558 (1915). 9 Photomicrographs, 5 Ternary Diagrams.

The author gives contour map of the liquidus surface of the ternary system Sb-Pb-Sn, also a structural diagram showing the constituents of the various fields. The constituents are also shown in photomicrographs. There is a strong tendency to segregation in some fields.

Effect of Rate of Cooling. Chill castings were made in iron molds at 0°, 250° and 650° C. The pipes formed in all the rapidly cooled

castings, and those with over 30 per cent Sb had many small holes and pores in addition. All were free from segregation. The castings in the preheated molds were free from piping. In Sb-rich alloys a few small holes were visible, but in the 10 per cent Sb alloy there were often great shrinkage spaces. The castings with the 10-30 per cent Sb segregated badly. Sb rich alloys of high melting point showed tin oxide crystals, these being more numerous the higher the temperature and the longer the heat had been applied.

Properties. The temperatures of the solidus surface in the different fields are given in the form of a table. The values of ball hardness (Martens) for the chill cast alloys are given in the form of a triangular diagram covering the whole field. In general, tempering causes an increase of hardness in Sn rich alloys and decreases it in Pb and Sb rich ones. Other triangular diagrams give the impact strength and the per cent compression at failure up to 40 per cent Sb. The impact strength is about 25 per cent lower at 100° than at 20° but at —20° it is about the same as at 20° C.

Conclusions from Compression Tests. (1) Sb free alloys may be compressed 50 per cent without cracking. (2) Alloys with 10 per cent Sb; the ultimate compressive strength (13,500) decreases with Pb content to a minimum at 50-60 per cent Pb (ultimate compressive strength = 13,500 pounds per sq. in.). (3) Alloys with 20 per cent Sb, ultimate compressive strength a minimum at 40 per cent Pb. (4) Alloys with 40 per cent Sb show a flat minimum and maximum (maximum at 40-50 per cent Pb).

Influence of Cu. As much as 2 per cent Cu completely eliminates segregation, due to the formation of a network of Cu rich needles which keeps the Sb rich cubes from rising. Addition of Cu introduces a new arrest point at a higher temperature than any of the others, while these are little affected. For constant Sb and Cu content, the melting point rises rapidly with increase of Pb, the alloys having considerably higher melting points than the Cu free ones. Addition of Cu increases the hardness, the effect being greater for the chill castings. The impact strength is also increased.

Commercial Alloys. A table of properties of 50 alloys of the system Sb-Pb-Sn from various sources is given, also a table of 30 other alloys, with their properties and uses.

Segregation. Alloys with less than 25 per cent Sb show increasing tendency to segregation with increasing Sn content, which reaches a maximum at about half the possible Sn content. This must be pre-

vented by rapid cooling, for instance in the case of large bearings by the insertion of chills in the mold (glyco skeleton bearing) or by the addition of Cu.

Hardness. The ball hardness reaches a maximum at Sb, 60; Sn, 30; Pb, 10. The brittleness generally increases with the hardness. However, alloys with less than 25 per cent Sb and rich in Sn are a decided exception, being hard but not brittle, though they are not exceptional in regard to compressive strength. Hardness-composition is very similar to the relative compressive strength composition.

43. Studies on Bearing Metals. R. Förg, *Internl. Z. Metallog.*, 8:68-94 (1916). 25 Photomicrographs.

The author has made a study of 22 commercial tin base and 2 lead base white metals. He identifies constituents in the photomicrographs and gives arrest points corresponding to their separation for some of the alloys. Type of structure of the Sn-Sb-Cu alloys is: Cu_3Sn needles, SbSn cubes and a soft matrix of ternary eutectic of high Sn content. The needles separating out first form a network which prevent the cubes from sinking and allow a more uniform structure. The cubes are harder than the matrix and carry the shaft. They stand slightly higher than the matrix and the lubricant circulates in between them. The size of the cubes depends on rate of cooling. If this is very rapid the Sb may be even held back in the eutectic.

It was formerly believed that a white metal should be as plastic as possible and Hg was added for this purpose. Förg tested alloys with as high as 6 per cent Hg but regards it useful only in small amounts as a deoxidizer on remelting metal. A double eutectic is present in slowly cooled alloys containing Hg. These alloys are more sensitive to the rate of cooling and the pouring temperature than the ordinary white metals. Their disadvantages are: (1) the matrix is soft and tends to wipe; (2) the Hg content is not easily controllable on remelting; (3) there is danger of mercury poisoning of the foundrymen.

Effect of Replacing Sn by Pb. Up to 5 per cent Pb the structure is little changed, a Pb rich eutectic is formed, the hardness is lowered slightly and the melting point noticeably. With a still higher per cent of Pb a new constituent appears which is still softer than the Sn-Sb-Cu eutectic and causes a decrease of hardness and brittleness. The structure of alloys with a high Pb content (67-78 per cent Pb) is: β crystals (whose domain begins at Sn, 10; Sb, 10 in the system Pb-Sn-Sb);

small amounts of ε crystals (Cu-Sn needles) ; and a matrix of ternary eutectic containing 80 per cent Pb.

Replacement of Sn by Zn. In alloys of high Zn content the first constituent separating out on cooling is Zn-Sb in hard crystals, next appear hard β crystals of the system Sn-Sb (10 per cent Sn) and finally the ternary eutectic. These alloys are little used commercially on account of their high melting point (over 400° C.) which causes oxidation of the Sn, and special foundry methods are necessary on account of the high pouring temperature which is over 500° C. In alloys of high Sn content, which usually contain less than 10 per cent Sb, this latter occurs in solution in the Sn in the ternary eutectic. They are very similar to the alloys of the binary system Sn-Zn. The binary eutectic contains 90 per cent Sn. The primary separation is not conspicuously acicular, the SnSb cubes are present, and there is a double eutectic. In these alloys the matrix is harder than the embedded crystals, contrary to the modern idea of a bearing metal.

Pouring temperatures from 350° C. to 950° C. had little effect on the structure or the hardness of Sn, 84; Sb, 10; Cu, 5; Pb, 1 or Sn, 77; Sb, 1; Cu, 1; Pb, 0.5; Zn, 20.

The rate of cooling had great effect on the structure. Both alloys were poured into chill molds at 0° C. and again into preheated molds and slowly cooled. In the latter case the size of the Sn-Sb crystals was about ten times that in the former, and the structure was much coarser throughout.

Effect of Remelting. Heyn and Bauer had found slight Sn and Sb loss in remelting Sn-Sb-Cu alloys. In alloys containing Hg the content of this was varied on remelting, but to what extent was not determined experimentally, as this alloy was unsuitable for bearings. A Sn base alloy containing 20 per cent Zn lost about 3.5 per cent Zn after 6 remeltings, the effect on the structure being evident from the photomicrographs.

Segregation. Of four alloys, Sn, 84; Sb, 10; Cu, 5; Pb, 1 showed the least segregation. Shrinkage spaces were present in a 20 per cent Zn alloy, due to expansion of the Zn crystals on freezing and to their contracting after the surrounding eutectic is frozen. This effect was greater for slower cooling.

The specific gravities of five alloys are given.

Hardness. The addition of Hg has no effect on the ball hardness although the matrix must be softer. The hardness of the Cu-Sb-Sn system is not altered by remelting but is greatly affected by the rate

of cooling. The hardness of Zn containing alloys is lowered by remelting. Sb and especially Cu increase the hardness and brittleness. The ranges in practice are: Cu, 5-10 per cent; Sb, 10-20 per cent.

Abrasion Tests (by means of rotating shaft covered with emery paper rubbing on the test piece). Sn, 84; Sb, 10; Cu, 5; Pb, 1 gave the most uniform results. Loss was least for the Zn containing alloys as these glazed the emery paper (Hubert 1F), thus exhibiting an undesirable property for a bearing metal.

Förg concludes that Sn, 84; Sb, 10; Cu, 5; Pb, 1 and similar alloys are the best for bearing metals of those tested, having the following advantages over the Hg and Zn containing alloys: (1) little changed by remelting; (2) little tendency to segregation and none to cavitation; (3) they do not wipe, the structure of hard crystals in a softer matrix being conducive to good lubrication; (4) the melting point is 30-40° C. higher than that of the Zn alloys, therefore there is less tendency to run out in service; (5) production and maintenance are easier than that of the other white metals.

44. White Metals, Part I. Antifriction Alloys. A. H. Mundey, C. C. Bissett, and J. Cartland, *J. Inst. Met.*, 28:141-183 (1922). 8 Photomicrographs.

The exact physical properties desirable in a lining for a bearing are not generally agreed upon. It is admitted that in the ideal case there is no contact between shaft and bearing. As this condition is never perfectly fulfilled it is important to choose a bearing metal which will meet the mechanical conditions and also present the kind of surface which will tend to spread and maintain the oil film.

Experience has established the opinion that a homogeneous metal or solid solution is not suitable for a bearing but the structure should be one of hard crystals in a soft matrix or a hard metal interspersed with veins of a softer constituent. The authors' opinion is that the hard parts stand in relief providing channels for the oil, the spread of oil over the surface being allied to the phenomenon of capillarity.

Mechanical tests were made on nine representative alloys. (See Table 7.)

Service tests consisted in running sets of bearings under service conditions for a certain time, if possible several months, giving them constant attention. Laboratory trials are more accurate but do not represent working conditions. The authors ran a series of tests on a

Thurston machine, but the comparisons are not always valid as the different alloys are used for different purposes.

In tin base alloys the Cu-Sn ε crystals solidify first and entangle the cuboid Sn-Sb γ crystals which form subsequently and prevent segregation.

The functions of tin and lead base alloys are similar. The chief differences are the action of the Cu-Sn crystals in the tin base alloys and that the matrix of the tin base alloys is tougher.

Greatest skill should be used in handling to avoid over-heating and to avoid leaving the hardening constituent in the ladle by liquation.

The paper was discussed as follows:

Sir Henry Fowler had the impression that No. 2 (see Table 7) was the alloy most used in aero work. One point of great importance in locomotive and motor car work was the question of resistance to alternating pressure, it being necessary to have a metal which would not spread when it received a blow. The alloy 85:10:5 was used almost universally for locomotive purposes and for other engines where repeated stresses occurred. Some railroads had found it possible to use an alloy similar to No. 7, while No. 7 was used very extensively where there were no changes of stress. He states that trouble with hot bearings was sometimes due to the fact that the cuboid crystals stood in too high relief, the eutectic having melted away from between them, and points out the necessity of temperature control, which is difficult when pouring from a ladle.

Dr. W. Rosenhain felt a little doubt about the oil channel theory as he does not believe that the hard crystals stand long in relief after the pressure is applied. He had yet to find a case where there was an appreciable difference in level in a worn bearing. The hard constituent was necessary to support the bearing pressure but itself needed the plastic support of the softer material as otherwise the hard crystals were liable to cleave. He thought that a film of the softer material flowed over the hard and acted as a lubricant. Or maybe this film was a conglomerate of oil and metal as some evidence tended to show.[*] The nature of the metal plays a part in lubrication. Rosenhain criticizes the authors' statement on overheating. If the metal is overheated and allowed to cool down before casting the effect on the structure would be practically nil.

In correspondence that follows the authors give an account of fric-

* Work of Hardy and his colleagues.

tion machine tests by the Great Western Railroad. Priestly gives tables of the results of some of his experiments. (See Tables 9-10.)

45. Babbitt Metals—Their Character and Uses. L. D. Allen, *Raw Material*, 6:56 (1923).

Allen gives the effect of additions of Sn, Bi, Pb, Sb, and Cu to bearing metals. (See Abstract No. 60.) He classifies babbitts into tin base (70-90 per cent tin), semi-tin base (30-60 per cent tin), and lead base (0-20 per cent tin).

For general heavy duty service a lead base metal is suitable; for extra heavy duty, as for light type crushers, cement mills, etc., a semi-tin metal containing copper may be used; for extreme speed and heavy duty service or for bearings subjected to vibration and shocks a tin base alloy should be used. The requisites of a satisfactory liner are enumerated. Strength should be obtained through the use of Cu rather than by too much Sb which increases brittleness.

46. Lead- and Tin-Base Bearing Metals. R. Kühnel, *Verkehrstech.*, 1927, p. 858. (Abstract by Przygode.)

The author attempted to find a figure of merit for bearing metals. He carried out the most varied mechanical and physical tests on these alloys. Treatment in service is a large factor in the life of a bearing. The author concludes that tests of finished bearings in special test machines are to be preferred to results that have to be further worked up.

47. Diesel Marine Babbitt. Anonymous, *Am. Machinist*, 61:169 (1924).

Diesel Marine Babbitt is manufactured by the Union American Metals Corporation, Deane St. and Meserole Ave., Brooklyn, N. Y., according to government specifications by the Stanley process. The ingredients are separately melted and continuously agitated for 24 hours. This keeps the tin at the proper temperature and insures homogeneity.

48. The Physical Properties of the American Society of Testing Materials Tentative Standard White Metal Bearing Alloys. J. R. Freeman, Jr., *Proc. Am. Soc. Testing Materials*, 22(1): 207-211 (1922).

Compressive strength, yield point in compression and Brinell hardness were determined at normal temperature and at 100° C. on

the 12 white metal bearing alloys adopted as tentative standards (129). Tables are given of analyses and pouring temperatures, also of the above properties and of the melting ranges.

In tin-base alloys, the yield point, ultimate compressive strength and Brinell hardness number increase with the Sb content; the difference is greater, however, at normal temperature than at 100° C. The presence of Pb lowers the compressive strength and causes·more rapid softening with increasing temperature. Alloys made under commercial conditions generally are harder at normal temperature than those prepared in the laboratory. Specimens 3 in. x 1 in. diameter gave the same results as those 1.5 in. x 0.5 in. diameter. The Brinell hardness number was slightly higher with the 100 kg. load than with the 500 kg.

49. On Lead-Tin-Antimony Alloys. O. W. Ellis, *J. Inst. Metals*, 19:151-154 (1918).

Tensile, compression and Brinell hardness tests were made on 21 alloys of the ternary system Pb-Sn-Sb containing over 64 per cent Pb. Tables of properties are given.

Ellis' conclusions are: (1) the effect of the presence of the SnSb compound is to render the alloys brittle and weak; (2) the general mechanical properties of the alloys containing less than 15 per cent Sn are improved by the addition of Sb in quantities not exceeding 10 per cent; (3) increasing the Sb content increases the hardness. Maximum hardness, however, is at about Pb, 70; Sb, 20; Sn, 10.

50. Thermit-Lagermetall. (Thermit Bearing Metal.) G. v. Hanffstengel, *Z. Metallkunde*, 15:107-108 (1923). 2 Photomicrographs, 1 Cooling Curve.

Lead is especially suitable as a base for a bearing metal on account of its antifrictional properties. The chief disadvantages of the usual hardening agents added to lead are: (1) the nature of the resulting alloy is such that the lead tends to segregate, which action is, however, hindered by the presence of Cu; (2) when Cu is used to harden Pb, the pouring temperature increases out of proportion to the hardness.

The Th. Goldschmidt Aktien Gesellschaft has succeeded in producing a Pb-Sb-Sn alloy, of low Sn content and containing small additions of Ni and a few other elements, which, while hard, has a moderate pouring temperature. Solidification begins at 429° C. so the alloy may be poured at 480° C. The cooling curve has an arrest point

at 245° C. (softening temperature). The alloy is not changed by remelting, and with ordinary care shows little change even after 14 remeltings.

The frictional properties are about the same as those of a high tin base white metal. The Brinell hardness number is 33 at 20° C. and 18 at 120° against 13 for white metal at 120° C.

Thermit has been used with success under heavy loads in the main bearings of compressors, armature bearings of street railroad motors and middle bearings of briquette presses, also for high speed applications. Its low price allows it to be used also under less severe conditions and to take the place of a variety of different alloys.

51. The Original Babbitt Metal Formula. Anonymous, *Brass World,* 1:325 (1905).

Isaac Babbitt was not the inventor of the metal named after him, but was the first to use it for bearings. His original patent, U. S. No. 1252, July 17, 1839, is for the mechanical construction of bearings and not for the metal. In his specification, he says, "The inner parts of boxes may be lined with any of the harder kinds of composition known as Britannia metal or pewter of which block tin is the base. An excellent compound for this purpose consists of fifty parts tin, five parts of antimony and one part of copper, but I do not confine myself to this particular composition".

It will be readily seen that there is not an original babbitt formula. The mixture which he suggests has been found to be too soft for ordinary work.

52. Investigations on Bearing Metals. E. Heyn and O. Bauer, *Stahl Eisen,* 31:509-512 (1911). (Abstract from *Mitt. Material-prüfungsamt,* 1911, Heft 1.)

A study was made of the properties of a tin base white metal, the specifications (Prussian Railroad Administration) for which were: Sn, 83.33; Sb, 11.11; Cu, 5.55.

Effect of Remelting.

As made up:	Sn, 83.10; Sb, 11.10; Cu, 5.43.
Remelted once:	Sn, 86.43; Sb, 8.76; Cu, 4.51 plus impurities.
Remelted 5 times:	Sn, 85.86; Sb, 8.58; Cu, 5.33 plus impurities.

The loss of Sn and Sb was due to oxidation but there was no trace of inclosures of oxide, dross, etc. Remelting causes no apparent change in the structure. Ball-hardness is little changed by remelting.

Microstructure. Dark: tin rich matrix; bright: Sb-rich cubes; bright: Cu-rich needles.

Cooling Curves. Curve of cooling times are given. The Cu-rich needles crystallize out at 366° C., the Sb rich cubes begin to crystallize at 264° C. and the eutectic point (solidification of the matrix) is at 238° C.

Constituents. The crystals were separated by means of alcoholic HCl. Analysis showed the cuboid crystals to be mixed crystals containing equal parts of Sb and Sn and the Cu rich needles mixed crystals containing Sn with 31 per cent Cu.

Influence of Pouring and Mold Temperature. The same structural constituents were present in all the castings made. Mg and Al used as deoxidizers had little effect on the microstructure. Cold or preheated iron molds were used.

(a) When poured at 400° C. into a cold mold the cubes and needles were small.

(b) When poured at 700° C. into a cold mold the cubes were small and Cu rich needles collected in chains of small ones.

(c) When poured at 400° C. into a preheated mold the size of the cubes greatly increased with a tendency to stellate arrangement of Cu rich crystals.

(d) When poured at 700° C. into a preheated mold the size of the cubes and needles increased, with the latter grouped in chains.

Fractures. (a) Fine-grained, matte grey; (b) fine-grained, bright; (c) and (d) coarsely crystalline, shining. Chill castings piped, others had flat top.

Special Phenomena. Melts deoxidized with Al showed the bloom of alumina after several weeks, especially on the cut faces and the pipe. There was nothing similar with Mg.

Mechanical Properties. The chill castings are considerably harder. Mg and Al cause a slight increase in the hardness of the alloys cast at 400° C. The hardness of a bearing lining was intermediate between that of the castings in the chill and the preheated molds.

In the impact (hammering test) the chill castings absorbed greater energy before cracking. In the castings poured at 400° C., Mg and Al increased the resistance to hammering in the chill cast alloys but decreased that of the others.

The compressive strength was less influenced by the speed of cooling than was the preceding property. Chill castings stood somewhat higher loads, and the yield point in general was higher.

The authors conclude that the addition of Al or Mg is superfluous, and might develop harmful properties.

53. Plastic Babbitt Metal. Anonymous, *Brass World,* 4:99-100 (1908).

"Richards Plastic Babbitt Metal" has been made in England for some years. If heated to just below its freezing point it becomes plastic and may be worked like plaster. Analysis shows it to be Sn, 82.43; Sb, 9.47; Cu, 8.10; Pb, 0.0. The metal is poured into the backing, and when it becomes pasty it is worked into shape by a stick of wood. The surface may then be hammered or turned to shape.

54. A Bearing Metal Containing Calcium. Hart, *Metalltech.,* 46:73 (1920). [From *Chem. Tech. Übersicht,* 44:220 (1920).]

Calcium bearing metal is a substitute for Sn base white metals and contains lead with a number of other metals. Part of the Pb enters into chemical combination with the Ca which separates out as harder crystals from the softer Pb rich matrix. The matrix is harder than pure Pb but elastic. The elastic limit in compression is 2000 kg./mm.² (2850 pounds per sq. in.), which is 2.5 times that of 80 per cent Sn white metal. (Brinell hardness number = 35-45; melting point = 370° C.; pouring temperature = 450-480° C.).

The alloy is best melted in clean iron kettles free from Zn. Graphite crucibles are to be avoided on account of the formation of calcium carbide. Linings of this alloy should not be less than 18 mm. thick. The bearing shell should be tinned and preheated as hot as possible so as to solder the lining to the back.

55. Lead-Calcium Alloys. R. T. Rolfe, *J. Inst. Metals,* 25:171-174 (1921). 1 Photomicrograph. (Communication after Brace's paper: Some Notes on Calcium.)

The author found a proprietary oil engine bearing alloy to be: Pb, 97.05; Ca, 0.79; O, 0.66; As; Cu; Fe; Zn. The structure was hard crystals of a Pb-Ba-Ca compound in a Pb rich matrix. It was made by an electrolytic process and was much harder than pure Pb.

	Brinell Hardness Number		Scleroscope	
	500 kg.	1,000 kg.	Ordinary	Magnifier
"Hardened" lead	31.2	26.5	7.5	13.5
Ordinary lead	8	...	2	3

The alloy emits a "steel like" ring when struck. It is claimed to have stood up to 6000 pounds per sq. in. in properly designed bearings with satisfactory results.

There is much more dross in melting, particularly if stirred, than in the case of Sn base white metals, due to the oxidation of Ca and Ba. It should be melted only as needed, poured at 450° C., the mandrel being fairly hot. If feeding is not carried out, a shrinkage cavity will form just below the point where the metal is run in.

The alloy does not possess so great an advantage on the score of cost as might be expected of one containing 98 per cent Pb. The author claims that the alloy stands high temperatures better than white metals, and that the decrease in hardness is less up to 200° C.

56. Calcium-Lead Bearing Alloy. L. Filipoff, *Metal Ind. (London)*, 22:145-147 (1923). 2 Photomicrographs, 1 Cooling Curve.

Advantages: The alloy softens at 300° C. as against 180-220° C. for tin-base white metals. Most lubricants boil at about 250° C., therefore a hot bearing is made evident by the smell of oil before damage is done. The hardness and wear resistance are greater and the coefficient of friction is less than for the tin-base white metals.

Disadvantages: Alloys are more easily oxidized when melting and they must be melted in a comparatively small iron crucible, kept covered with charcoal. Bearing pillows must be heated to a higher temperature corresponding to the higher casting temperature. Since the alloy cannot be soldered to either copper or iron pillows by tinning the latter, a special shaped pillow is needed.

Structure: Pb; Ca, 1.90; Sr, 1.00; Ba, 1.10; Cu, 1.37; Na, 0.10. Very hard crystals of Ca-Cu rich in Cu and less hard crystals of Pb with alkaline earth metals are embedded in a matrix of two eutectics, one hard and rich in Ba and the other soft and rich in Pb.

Properties: The total linear contraction $= 0.77$-0.79 per cent (about half that of a Cu-Sn-Zn-Pb alloy). The casting temperature (600°-750° C.) has little effect on the grain size and the segregation. The resistance to compression $= 23,500$ pounds per sq. in. at 15° C. and 16,000 pounds per sq. in. at 100° C. The Brinell hardness number $= 27.9$ at 15° C.

57. Lead-Calcium-Barium Alloys as Bearing Metals. A. M. Bochvar, *J. Russ. Met. Soc.*, 1925 (I), pp. 137-139. (Abstract in *Chem. Abstracts,* 21:3036 (1927).

This article discusses: "an experimental investigation of bearing metals with a lead base containing alkali and alkaline earth metals. The alloys were manufactured electrolytically from molten chlorides with a cathode of molten lead. There was added 16 per cent of CaF_2 to $CaCl_2$ and 30 per cent of KCl to $BaCl_2$. Remelting caused heavy losses in calcium and barium. Binary alloys of lead and barium up to 5 per cent of the latter, and ternary alloys up to 1.5 per cent calcium did not show any segregation. Ternary alloys with more than 1.5 per cent calcium, on the contrary, would easily segregate. Alloys of lead and barium with over 4.5 per cent barium easily oxidized in the air. An alloy of 14 per cent barium would disintegrate to a powder upon exposure to the air. Ternary alloys of 0.5-2 per cent calcium and of 0.6-4.0 per cent barium were practically stable in air and in water. The Brinell hardness number of the alloy Pb, 97; Ba, 2; Ca, 1 was 27. An increase of hardness with time was observed; thus an alloy containing 1 per cent Ca, and 1 per cent Ba increased in Shore hardness during 28 days from 9 to 12. Metallographic analysis showed the presence of the compounds Pb_3Ca and Pb_3Ba. In the alloys of lead and calcium, the compound Pb_3Ca is embedded in a matrix of lead. In the alloys of lead and barium up to 5 per cent of the latter, the structural components are lead crystals and the eutectic Pb_3Ba-Pb; if the barium content becomes over 5 per cent then the same eutectic is coupled with the crystals of the compound Pb_3Ba. The eutectic melts at 290° C. The best etching reagent for these alloys was 0.1 per cent HNO_3. Useful antifrictional properties can be obtained in the ternary alloys of lead with both calcium and barium; the binary alloys of lead and calcium are too soft when containing a small amount of calcium, and segregate too readily when the percentage is large. The binary alloys of lead and barium, when sufficiently hard, easily oxidize."

58. Bahnmetall, the New Kind of Bearing Metal. Anonymous, *Verkehrstech.*, 1927, pp. 28-29.

A prime essential in the economical operation of railroads is the choice of suitable bearing metals, which are reliable and not too expensive.

In recent years many laboratory and service tests have been carried

out on various new bearing alloys containing little or no tin with view of eliminating this expensive foreign metal. Some degree of success had been obtained before the advent of Bahnmetall. This alloy, called "Bn" metal for short, stands up under the highest loads as well as or even better than ordinary white metals, in spite of the fact that its cost is only about one-fourth that of the high tin alloys.

Bn-metal consists essentially of lead hardened by the addition of alkali and alkaline earth metals. Its Brinell hardness at room temperature is several units higher than that of Regelmetall, and its compressive strength and plasticity are about the same as those of Regelmetall. Its transverse strength, however, is much higher than that of any other white bearing alloy, being greater than that of Regelmetall in the ratio 23:13.

One advantage of this alloy is that it maintains its hardness when hot. At its normal running temperature of 60-70° C., the Brinell hardness of Bn-metal is 8-10 units higher, and at 100-125° C. it is 10-12 units higher than that of Regelmetall. Regel has very poor strength at these temperatures, which leads to hot boxes and to melting out of linings. Due to its higher hot-hardness and its higher cold-melting point (320° against 232° C. for Regel) Bn is only partially squeezed out but is not melted. Before still higher and dangerous temperatures are reached, attention is called to the hot box by the oil vapors. When rolling stock develops hot boxes, therefore, it need not be cut out of a train, but can go itself to the shops, which is a very great advantage from an operating standpoint. With suitable lubrication hot boxes will not occur even if the bearings are overloaded, because temporary overheating causes no harm.

The casting of Bn-metal gives no difficulties in up-to-date foundries. Railroads not wishing to undertake the casting of this metal can get finished bearings from the firms supplying Bn-metal. Finished bearings can, after suitable treatment (oiling or coating with paraffine), be stored for months without the least hesitation.

The German Reichsbahn Gesellschaft uses Bn-metal exclusively in its standard car bearings. Moreover several passenger and freight locomotives have had their axle and rod bearings equipped with this metal with excellent results. Other transportation systems have also recognized the superiority of Bn-Metal and extensive service tests have led them to use this material exclusively for lining bearings.

59. The Electrolytically Produced Calcium-Barium-Lead Alloys Comprising Frary Metal. Wm. A. Cowan, L. D. Simpkins, and G. O. Hiers, *Trans Am. Electrochem. Soc.*, 40:27-49 (1921).

These alloys, patented by F. C. Frary and S. N. Temple (U. S. 1,158,671-5) are produced by the electrolysis of a mixture of Ba and Ca salts of low melting point using a molten Pb cathode and a graphite anode.

Frary metal is essentially a Pb-Ba-Ca alloy with small amounts of other elements. It contains up to 2 per cent Ba and up to 1 per cent Ca, the balance being Pb. As much as 0.25 per cent Hg and smaller amounts of other elements may be added.

For the constitution of Pb-Ca alloys see Ref. No. 247, and for Pb-Ba alloys see Abstract No. 84.

Addition of Ca up to 6 per cent raises the melting point from 320° C. to 640° C. due to presence of the high melting point compound Pb_3Ca. (Crystals of this occur in a matrix of Pb.) Other compounds exist with higher melting points (up to 1100° C.).

Addition of Ba up to 4.5 per cent lowers the melting point, Pb_3Ba and Pb forming a eutectic containing this percentage of Ba and melting at 291° C. The structure is a eutectic with an excess of Pb according to its composition.

In the Pb-Ba-Ca alloys, the eutectic forms at 284° C., otherwise the structure is what would be expected from a combination of the binary alloys. There is some evidence for solid solutions containing up to 0.2 per cent Ca and 0.4 per cent Ba.

The authors give table of critical temperatures for some of the alloys. The liquidus of a ternary alloy system lies above and the solidus lies below the melting point of Pb. The melting range is greater than with the Sn base white metals. The oxidation is no greater than with these latter at the same temperature.

The hardness of Frary metal is greatly increased by ageing, especially for alloys of low Ca and Ba content. The hardness of Pb; Ca, 0.7; Ba, 0.4 nearly doubles in 27 days. The hardness of the metal may also be doubled by heat treatment. The ageing period may be shortened by the addition of other elements.

Frary metal compares favorably with Sn base metal for bearings. Remarkable antifrictional properties are claimed, while retaining the plasticity of Pb. The structure is more similar to the Sn base than to the Pb base metals. Frary metal maintains its strength better at elevated temperatures than the babbitts.

60. Lead-Alloy Bearing Metal Developed. Anonymous, *Elec. Ry. J.,* 59:647 (1923).

Frary metal is an electrolytically produced Pb-Ba-Ca alloy. Good antifrictional properties are claimed for it, also hardness and strength at high temperatures. Under working conditions it develops a fibrous structure and a high polish.

The tensile strength = 13,000 pounds per sq. in.; Brinell hardness number = 20-30, the density = 11, the melting point = 621° F. (327° C.), the pouring temperature = 800° F. (427° C.), the specific resistance = 188 ohms per mil. ft.

Results of service tests by seven electric railways are given.

61. Tempered Lead. Anonymous, *Brass World,* 1:231-232 (1905).

"Tempered Lead" or "Noheet" has been on the market for a year or so. It appears to be similar to pure lead except that it is much harder and is somewhat resonant. Many analysts do not appear to have detected the alloying ingredient and therefore have assumed that the article is really tempered lead.

An analysis by E. S. Sperry shows the alloying ingredient to be Na. Analysis gives Pb, 98.51; Na, 1.30; Sn, 0.08; Sb, 0.11, the two last elements apparently being impurities.

As far as is known no * patents have been granted, nor is the alloy believed patentable as Pb-Na alloys have been known for some time, though not used for antifriction metals.

In making up the alloy the amount of Na should exceed that given by the analysis (say use 2 per cent) to allow for Na loss. The Na should be added immediately after it is removed from the oil. The presence of any moisture is liable to cause an explosion. After the metal is poured it should be covered with thick oil until it sets, to avoid oxidation of Pb. The ingots should be kept covered with paraffine, oil, or even lacquer.

If more Na is added than is called for above, the alloy will be brittle.

62. A Bearing Metal of High Elastic Limit. Anonymous, *Iron Age,* 95:1016 (1915).

"Noheet" is an alloy containing about 97 per cent Pb and hardened without Sb, Cu, or Zn. It is manufactured by the Lubricating Metal

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* Apparently this alloy was manufactured under U. S. Patent 803,921 of Nov. 7, 1905, issued to F. W. Moffett.—ED.

Company, of New York. At a compressive stress of 13,000 pounds per sq. in. on a specimen 1 in. x 1 in. diameter, the set is 0.0086 in. An elastic limit of 11,000 pounds per sq. in., about twice that of genuine babbitt, is claimed. The compressive strength = about 22,000 pounds per sq. in., tensile strength 13,000 to 15,000 pounds per sq. in. As the composition is varied to raise the elastic limit the compressive strength is lowered.

"Noheet" is claimed to have the natural lubricating qualities of Pb and a coefficient of friction 25 per cent less than that of any other bearing metal. It is adapted for high speeds as well as heavy duty. It is impregnated with an alkaline substance so that in contact with water a slight saponification results and consequent increase in lubrication.

The alloy melts at 589° F. (310° C.) but should be poured nearer to its melting point than tin base metals. Putting in brass strips should be avoided. There is no wear on the shaft even though mill scale happens to fall in the bearings.

63. Ulco Hard Metal. F. C. Frary and S. N. Temple, *Chem. & Met. Eng.*, 19:523-524 (1918).

Ulco metal was developed in the course of search for a substitute for Sb in hardening lead. Ca was tried first but considerable must be used to bring the hardness up to that of antimonial lead (Brinell hardness number = 17). The alloy also did not stand remelting well, but easily lost Ca. The discovery was made that if two or more alkaline earth metals were added to Pb the hardening effect was several times that found if only one were present in the same total amount. An alloy was developed which could be remelted several times without loss of hardness and which actually contained well over 99 per cent Pb. This is covered by United States Patents 1,158,671-1,158,675 inclusive.

The castings are free from blow-holes, the metal expands to fill the voids.

Tests were made at the United States Bureau of Standards with the following results: A 10 pound ingot of Brinell hardness number = 25.2 was melted down and chill castings poured at temperatures from 650°-1000° F. (345°-540° C.). Little change in Brinell hardness number resulted. Bearings made of Ulco metal proved much superior to genuine babbitt in a lubricated service test. The babbitt bearing ran only 6,600 revolutions at 400 pounds per sq. in., while an Ulco metal one was still running in good condition after 23,000 revolutions ·at

1,000 pounds per sq. in. The Ulco metal bearing ran cooler, its friction was less and its wear smaller. Its volume loss was still smaller due to the greater specific gravity. A bearing of Ulco metal was run dry at 700 revolutions per min. and 50 pounds per sq. in.; the metal flowed and adhered to the shaft after 10 minutes, but the shaft was not damaged.

Caution. If more than a small amount of Sb is added to the alloy, the alkaline earth metal separates out and the alloy is ruined.

Ulco metal is not brittle like antimonial lead. A pronounced increase in hardness takes place on ageing, which may be accelerated by the use of steam heat. An alloy with a Brinell hardness of 8 as cast, increased in Brinell hardness to 20.7 after 15 days, but if aged for one day at 212° F. (100° C.), the Brinell hardness rose to 25.4.

Alloys with small amounts of the alkaline earth metals appear to be true solid solutions.

64. Lumen Metal. J. L. Jones, *Metal Ind. (N. Y.)*, 17:283 (1919).

In answer to a query regarding flaky Lumen metal of composition Zn, 88; Cu, 10; Al, 10, Jones replies that the original formula was Zn, 85; Cu, 10; Al, 5. Cu and Al should be melted together in a crucible and poured into Zn which has been melted separately in a Schwartz furnace. When pouring, it should be cooled as low as possible and poured rapidly, using large gates.

Lumen metal is essentially a die-casting alloy, and is usually poured into metal molds. Very satisfactory bushings can be made by pouring directly into iron molds with no pressure except the static head of metal in the gates. If a somewhat softer metal is desired use Zn, 88; Cu, 4; Al, 8. By using "Horsehead" zinc an alloy may be obtained having a tensile strength of 40,000 to 50,000 pounds per sq. in., but no appreciable ductility.

In answer to a similar query (p. 334) Jones states that like all alloys containing Al, Lumen metal has a tendency to form an emulsion with the air present in the mold, hence it should be run into the mold with as little agitation as possible.

65. Lumen Bronze. Anonymous, *Handbook for Engineers and Machine Designers*, Lumen Bearing Co., 1922, pp. 17-18.

Lumen Bronze, having the composition Zn, 86; Cu, 10; Al, 4 is made by the Lumen Bearing Company, of Buffalo, N. Y. Its properties are given as follows:

Tensile strength .... 32,000–36,000 pounds per square inch
Elongation in 2 inches.................... 0
Reduction in area........................ 0
Permanent set of cylinders 1 inch high and
  1 square inch cross section:
    Under compression load of 25,000 pounds   0.001 inch
      "   "   "   " 75,000   "   0.1   inch
Brinell hardness number.................. 114–119
Pattern maker's shrinkage................ ⅛ inch per foot
Specific gravity 6.9
Density .... 0.25 pound per cubic inch

The alloy was patented by Prof. R. C. Carpenter of Cornell University and its metallurgy perfected by Mr. C. H. Bierbaum.

"The high compressive strength of Lumen bronze combined with its excellent anti-frictional qualities, make it an ideal metal in pivot bearings for turn-tables and swing bridges; for cold neck rolling mill table bearings, and crane bearings.

"It is a standard bronze in electric motor bearings, and in machine tool construction has a recognized place.

"Owing to its high compressive strength, it should be accurately fitted when put into service; and since this alloy has a higher coefficient of thermal expansion than red bronzes, caution should be taken to provide for the same under service conditions.

"The capacity of this metal to retain an oil film after it has been once established is almost unparalleled. It is for this reason that electric motor bearings made therefrom are giving such universal satisfaction. It is the one alloy that has never scored a journal.

"While other high zinc alloys have been tried out, none have met with such signal distinction owing to the extreme difficulty of combining the elements of this alloy and of avoiding deteriorating impurities".

66. Outlines Properties of Die Castings. C. Pack, *Foundry*, 48:695 (1920).

Die casting is best adapted for alloys of low melting point such as: Zn-Sn, Zn-Cu, Zn-Al, Sn-Cu-Sn-Pb, Sn-Sb, Pb-Sn, Pb-Sb, and Al-Cu.

The author gives a table of some typical die-casting alloys with their uses, which appears on the following page.

The cost of die casting cannot be computed on a pound basis since it depends on the design of the piece, the number and the position of the cores, the quantity produced, etc. Sn alloys cost most, then in order of decreasing cost Al, Zn, and Pb.

Composition and Uses of Some Typical Die-Casting Alloys.

	Composition Per Cent				
No.	Sn	Cu	Pb	Sb	Remarks
1	90	4.5	0	5.5	Genuine habbitt for main and connecting-rod bearings.
2	86	6	0	8	Harder than No. 1, for internal combustion engines.
3	84	7	-0	9	Harder than No. 2, for high-grade motors.
4	80	0	10	10	Light stationary motors.
5	61.5	3	25	10.5	Light duty cheap cars.
6	0	0	83	17	C.T. (coffin trim), light duty bearings.
7	0	0	90	10	Softer and more ductile than No. 6.
8	10	0	80	10	Light duty bearings.
9	5	0	80	15	Harder than No. 8, but less ductile.

67. Graphite Antifriction Metal. Anonymous, *Brass World*, 2:271 (1906).

Various attempts have been made to produce an antifriction metal that will contain graphite. Some time ago a metal marketed under this name was found to contain no graphite, but was simply Pb, 80; Sb, 20. It had a coarse black fracture somewhat resembling graphite.

A recent attempt has been made in Germany to make an antifriction metal which actually contains graphite. A mass of coarse grains of graphite are embedded or held in a mold and a layer of copper then electro-deposited over them, using a regular acid copper-plating solution. Another layer of graphite is then placed over the Cu, and another layer of Cu deposited. The metal is thus built up in layers to the required thickness.

68. Graphite Bearing Metal. Anonymous, *Brass World*, 6:207 (1910).

These alloys, originating in Germany, cannot be poured, for the graphite will be lost, but they must be shaped by machining. Their manufacture is based on the fact that some alloys become plastic at a certain temperature. (For instance Sn, 90; Cu, 10 at 420° F.) The graphite is incorporated under such conditions and the alloy then subjected to high pressure. Suitable alloys for mixing with graphite are: Sn, 90; Cu, 10 . . . Sn, 80; Cu, 10; Sb, 10 . . . Sn, 90; Ni, 10.

It is stated, but not confirmed, that graphite may be mixed with Cu-Pb.

69. Graphite Babbitt Metal. G. H. Clamer (Correspondence), *Brass World*, 6:251 (1910).

Clamer states that he produced the alloys of the preceding abstract 6 or 7 years previously, and applied for a patent covering them. A previous patent, however, existed which was broad enough to cover the same idea. This covered the introduction of graphite by subjecting the mixture of graphite and metal particles to pressure. Without pressure the process is of no value.

Clamer experimented with mixtures of other eutectic alloys and graphite. He did not have much success with Cu-Pb-Sn. The babbitt graphite mixtures were not very strong though perhaps he added too much graphite.

70. Durex, a Bearing Material Which Holds Oil Like a Sponge. Anonymous, *Automotive Ind.*, 50:1072-1074 (1924).

Durex, developed by the General Motors Corporation, is an absorbent, Cu-Sn-graphite bronze. Graphite exists in a finely divided state throughout the bronze and interlocked between the crystals. Its absorbent quality is due to the capillarity of many fine pores. Structure: alpha crystals of Cu-Sn as in ordinary Sn bronzes.

Durex will take up one-fourth its volume of lubricant and this can be removed again only by special methods. Oil can be wiped off the surface, but this becomes rapidly oily again. It will not score the shaft even if the oil is used up.

Durex is made in two grades: *Standard* for steady loads at a pressure x speed of less than 50,000 pounds per sq. in. x ft. per sec., elastic limit $=$ 2,000 pounds per sq. in., pores occupy 25 per cent of volume; and *No. 1* for piston pin bushings, crank-shaft main bearings and other uses under shock and heavy loading, elastic limit $=$ 4,200 pounds per sq. in., pores occupy 15 per cent of the volume. The composition of the two grades is the same, the difference being in the porosity. The composition may be varied for special conditions. It is not advised to make bearings of this alloy over 3 in. long. Lubrication required is as follows: plenty if the PV * is over 50,000 pounds per sq. in.-ft. per sec., little for a PV less than 50,000 and none if the PV is less than 20,000. The lubricant cannot wash the graphite out of the metal.

The author gives the design factors for bearings of this material and directions for installing them. A bushing mounted on a plug is

* Pressure X speed.

pressed into the shell, and the plug then withdrawn, the hole contracting 0.0002 to 0.0004 in. Reaming is detrimental to the surface. Any machining will close up the pores.

No details of manufacture, however, are given. The running clearances and the method of lubrication are given.

The coefficient of expansion for the standard is 16.9×10^{-6} per °C and for No. 1 is 15.1×10^{-6}.

70A. Durex. Anonymous, *Automotive Ind.*, 49:793 (1923).

The properties of Durex are given as follows: Brinell hardness number $= 30\text{-}40$ m., scleroscope hardness $= 15\text{-}18$, Young's modulus $= 2.5 \times 10^6$ pounds per sq. in., specific gravity $= 5.40$, elastic limit in compression $= 2000\text{-}10,000$ pounds per sq. in., depending on the composition.

71. Genelite—A New Bearing Material. E. G. Gilson, *Machinery*, 29:123-124 (1922). 1 Photomicrograph.

Genelite is a high grade synthetic bronze containing as high as 40 per cent of its volume of graphite in a finely divided state. It is made by heating the powdered oxides of Cu, Pb and Sn with an excess of graphite so as to partly reduce them. The powder is shaped in steel molds under high pressure and then heat treated (baked to sinter the metals together).* When polished, genelite is similar in appearance to bronze, but it is low in tensile strength while comparatively high in compressive strength.

Genelite is porous, allowing absorption of 2.5 per cent of oil by weight. In many places it may be used without oil grooves, the oil being fed from the outer surface by capillarity. It does not machine readily and is best shaped by grinding. It is most suitable for plain bushings. Owing to its low tensile strength it must be completely supported by the housing or backed up by a steel shell. It cannot be made as thin as a bronze bushing. An account of a severe service test is given.

72. A New Antifriction Alloy. R. F. Yates, *Sibley Eng. J.*, 32:6, 11 (1917).

Graphite in solid form is impregnated with molten metal under hydraulic pressure. Acheson graphite is especially suitable. The resulting product is named "Graphalloy". Graphite articles are placed in a graphite crucible containing molten metal, a partial vacuum is

* Detail from a shorter anonymous article on the same alloy in *Brass World*, **18**, 26 (1922).

first created to expel air from the pores of the graphite and then great pressure is applied. Graphite increases 150 per cent in weight, the metal content is 60 per cent by weight or 25 per cent by volume. Commercial production is at present limited to impregnation with babbitt and copper. Results of a dry run test on a Thurston machine are given. The operating temperature is considerably higher than that of ordinary oil lubricated bearings. The steel shaft gradually becomes coated with a film of graphite.

73. Manufacture of a Self-Lubricating Bearing Material. F. D. Jones (Signed F.D.J.), *Machinery*, 24:631 (1918).

Graphalloy is manufactured by the Graphite Metallizing Corporation, Yonkers, N. Y. It is used for bearings, bushings, brushes and contacts of electrical machinery.

Graphite for bearings is used in the form of bars containing a small proportion of amorphous carbon for strength and durability. These are first cut and ground to shape. The bushes are first heated at a relatively low temperature and molten metal then poured into the crucible. The pieces are kept submerged by a perforated plate. The temperature is next increased, copper is poured in at 1940° F. (1060° C.) and the melt superheated to 3000° F. (1650° C.). The crucible is then placed in the chamber of a hydraulic press and a vacuum created to expel air from the pores of the graphite. In two or three minutes the pressure is raised to 5000 pounds per sq. in. The process is complete in about 5 minutes. All except small pieces are immersed in sand for gradual cooling. The work is ground to size. Shaft bearings are impregnated with white metal. With babbitt the density is increased from 1.8 to 4. The compressive strength is 14,000 pounds per sq. in. approximately. The alloy is not injured by the lubricant. It can be used for light duty at high speed or heavy duty at low speed. The bearing pressure should not be over 50 pounds per sq. in. of the projected area, and the pressure $\times$ speed of not over 200 ft./sec.-pounds per sq. in. Graphalloy is a poor conductor of heat. It may be operated at temperatures of 200-300° F. (93-150° C.).

74. Crilley Mercury Bearing Metal. Anonymous, *Machinery*, 31:915 (1925).

Crilley mercury bearing metal has a soft plastic matrix held by a web of tougher material. It is claimed that repeated tests have shown that seizure will not occur even with no lubrication. It will not score

the shaft. At high temperatures it appears to exude a small amount of lubricant. It is claimed to expand at the same rate as the shaft. The alloy is distributed by the Metal Sales Company, 511 Bergen Ave., Jersey City, N. J., and is furnished in solid and cored bars. It is claimed to have a tensile strength of 23,000 pounds per sq. in. and a compressive strength of 92,000 pounds per sq. in.

74a. Rubber in Engineering. (In part.) J. W. Schade, *Trans. Am. Inst. Chem. Eng.*, 19:57-70 (1927).

Use of Rubber Bearings. The relatively low friction between metal and rubber which is wet with water has led to the use of rubber in bearings for boats, hydraulic turbines and deep-well pumps. These bearings are especially superior to babbitt or *lignum vitæ* if the water contains silt or sand. Grit does not embed itself in the rubber.

The author gives several examples of propeller bearings on boats, in which rubber showed practically no sign of wear after several months' service, although when bronze and babbitt bearings had been used in the same places they had to be replaced several times in the same interval. Rubber bearings have also given good service in a Nevada mine where exposed to the abrasive action of ore dust, under conditions where babbitt bearings only lasted a month. They have given much better service than *lignum vitæ* at a hydroelectric plant on the Susquehanna. Rubber bearings have permitted more economical operation of deep well pumps, in the words of a French report: "There is no appreciable vibration in the transmission and its operation is absolutely noiseless. The saving in power amounted to about three kilowatts per hour (50 hp. pump) and this economy paid for the installation in about three months." Rubber bearings showed slight wear after seven months in a coal-washing plant where bronze bearings lasted only two months.

75. Surface Flow Phenomena. J. E. Hurst, *Engineering*, 100:130-131 (1915). 5 Photomicrographs.

The formation of a surface layer of the amorphous phase of a metal has a large influence on its wearing properties. The least trouble and the best wearing properties are obtained from "glazed" engine cylinders, bearings, etc. A photomicrograph is given of the interior of an old cylinder showing no trace of structure, also one of a new cylinder showing a layer of the amorphous phase in the process of formation. If this is polished away and etched, the normal structure of the cast

iron is seen. The thickness of the layer is 0.001 to 0.005 in. in cast iron cylinders. The author examined a lower-end connecting rod bearing where the amorphous layer was one sixty-fourth in. thick.

The amorphous metal is harder, more tenacious and more readily attacked by etching reagents. The first action of the flowing of the metal is to fill up the tool marks. An orthodox bearing metal has hard particles embedded in a softer matrix. This is undoubtedly correct as far as it goes, but the mechanism of action of this type of structure is far more complex than appears on the surface. Bearings originally having a duplex structure are now running well with the whole surface covered by a layer of amorphous metal 0.01 in. thick.

76. A Note on White Antifriction Alloys. J. E. Hurst, *Metal Ind. (London)*, 22:357-358 (1923). 5 Photomicrographs.

A seized motor bearing was cleaned and microphotographed without etching. The structure of the metal was evident in the part that seized, but not in the other part. No traces of structure were seen in a bearing of the same metal that stood up in service.

This would seem to disprove the assumption that under conditions of running the hard crystals stand out in relief, leaving cavities for the distribution of the lubricant. Bearings examined by the author which did show structure were the ones which wore with undue rapidity. Rapid wear produces considerable of the products of disintegration which act as a relief polishing agent.

77. On the Transformations in Bronze, Aluminum-Bronze and Brass. T. Matsuda, *Sci. Rept. Tohôku Imp. Univ.*, 11:223-268 (1922).

Conclusions in regard to transformations of bronze are: (1) thermal analysis gives a eutectoid transformation at 530° C. on heating and at 505° C. on cooling; (2) discontinuous changes in length and electrical resistance occur at the eutectoid temperature; (3) specimens quenched from above the eutectoid temperature have a higher tensile strength and elongation and a lower hardness than those quenched from below the eutectoid temperature.

The eutectoid temperature of Al bronze is at 560° C., and there is a temperature difference of 60° between heating and cooling at the ordinary rates. Conclusions (2) and (3) above, apply also to Al bronze.

78. Investigations of Systems Forming Layers in the Liquid
    State (I. Lead and Copper). K. Friedrich, *Metall Erz.*, 1:575-
    586 (1913).

The author summarizes the results of previous work on this system
and reproduces the diagram of Heycock and Neville. This was deter-
mined from cooling curves, and while it is probably accurate over
most of the range, it does not give the mutual solubility of the two
liquid phases so accurately on account of the small heat effect involved.

The present author has investigated the solubility of the liquid
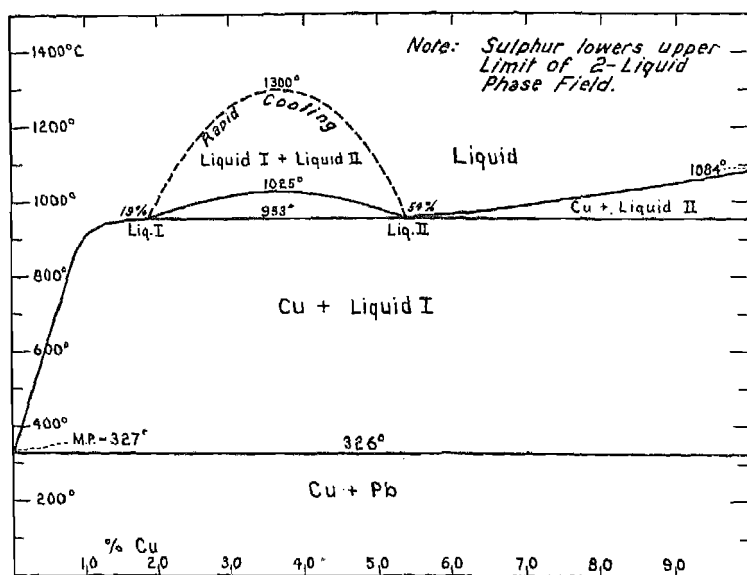
Fig. 1.—Equilibrium Diagram of the Copper-Lead System

phases by the method of Spring and Romanoff, using improved appa-
ratus and technique. The melt is stirred mechanically and then let
stand for a time. Samples of the melt are taken at different heights
in the crucible by means of a quartz pipette. Analysis of these samples
gives the composition of the two layers, or even shows variation in
composition within a layer.

The temperature of complete miscibility decreases with the time
of standing. For weak stirring and then standing for one hour this
temperature is about 1300° C., or at 1150° C., if the melt was rapidly
heated up to 1300° C. With strong stirring and 15 hours' standing the
temperature of complete miscibility was 1025° C. If the solubility

curve is flatter, the nearer is the approach to equilibrium. The composition limits of the two-liquid phase region are 19 and 54 per cent Cu. For Friedrich's equilibrium diagram see Fig. 1.

79. **Copper-Nickel-Lead Alloys.** W. Guertler and F. Menzel, *Z. Metallkunde*, 15:223-224 (1923).

The system Cu-Ni-Pb includes two binary systems which are not miscible in all proportions in the liquid state. Cu-Pb are immiscible between 36-86.5 per cent Pb and Ni-Pb between 30-84 per cent Pb. Cu and Ni are miscible in all proportions. However, by melting Cu, 75; Ni, 25 with Pb, the authors were surprised to obtain alloys whose constituents were miscible in the liquid state, and which did not segregate. The structure was mixed crystals of Cu-Ni in a eutectic matrix of practically pure Pb.

Alloys containing about 60 per cent Pb, about the middle of the regions of immiscibility in the binary systems, were investigated to find the approximate limits of these regions on the ternary diagram. It was found that miscibility of Pb and Cu could be brought about by 2.5 per cent Ni and that of Ni and Pb by 6 per cent Cu, therefore these regions occupy only a small part of the ternary system.

Very accurate determinations were not possible, since, as the nearer the head of this region is approached, the densities are more nearly the same, and there is correspondingly less tendency to segregate. Formations of emulsions occur which become more fine grained as the limit is approached and grade into perfect solutions.

These facts may explain the favorable effect of Ni on the equilibrium of the alloy Cu-Pb used for bearing metals and other purposes.

80. **Constitution of Tin Bronzes.** S. L. Hoyt, *Trans. Am. Inst. Mining Met. Eng.*, 60:198-205 (1919). 14 Photomicrographs.

Hoyt finds a heat effect at 575° C. in the alloy Cu, 79; Sn, 21 ($a + \beta$ field) in addition to one previously known at 520° C. The former heat effect is more marked in the Cu-Sn-Zn alloys rich in Cu and Sn at about 600° C. A series of photomicrographs shows a complete transition from the high to the low temperature modification.

80a. **X-Ray Analysis of the Copper-Tin Alloys.** A. Westgren and Gösta Phragmén, *Z. anorg. allgem. Chem.*, 175:80-89 (1928).

X-ray analysis has shown that the various phases occurring in the copper-tin system are structurally analogous to those of the copper-zinc system.

The lattice parameter of the *alpha* bronzes increases with the tin content from 3.608 Å for pure copper to 3.693 Å for the saturated solid solution containing a little over 15 per cent tin.

The *beta* phase, which occurs at higher temperatures, has a body-centered cubic lattice with a lattice parameter of 2.972 Å at 15 atomic per cent tin, the two kinds of atoms being distributed at random among the points of the lattice.

The phase which is sometimes called Cu_4Sn gives powder photograms which are very similar to those of the *gamma* phase in the copper-zinc and copper-aluminum systems. These photograms show the lattice to be face-centered with an elementary cube containing 416 atoms and an edge having a length of 17.91 Å. The phase is homogeneous at the composition corresponding to the formula $Cu_{31}Sn_8$. The valence electron concentration is then 21:13, the same as that of the fundamental compounds of the corresponding Cu-Zn and Cu-Al phases, which, according to Bradley, have the formulæ Cu_5Zn_8 and Cu_9Al_4 respectively.

The phase usually designated as Cu_3Sn has a hexagonal close-packed lattice, the parameters changing with the tin content from:

$$a_1 = 2.747 \text{ Å}, \quad a_3 = 4.319 \text{ Å}, \quad a_3/a_1 = 1.572 \quad \text{to:}$$
$$a_1 = 2.755 \text{ Å}, \quad a_3 = 4.319 \text{ Å}, \quad a_3/a_1 = 1.568$$

In this phase, also, the copper and tin atoms are distributed at random among the points of the lattice.

The phase occurring at about 60 per cent tin at low temperatures has the structure of nickel arseniate. The tin-saturated phase has the lattice parameters: $a_1 = 4.190 \text{ Å}$, $a_3 = 5.086 \text{ Å}$, $a_3/a_1 = 1.214$. The copper atoms in excess of the composition CuSn are contained within the body of the lattice and are distributed at random.

81. A Contribution to the Study of Phosphor-Bronze. O. F. Hudson and E. F. Law, *J. Inst. Metals*, 3:161-186 (1910). 22 Photomicrographs.

The authors refer first to the work on the binary systems Cu-Sn and Cu-P (by Heycock and Neville, and Heyn and Bauer respectively). In the latter system a Cu-Cu_3P eutectic is formed at 8.2 per cent P and 705° C., but Cu can dissolve more Cu_3P than Heyn and Bauer indicate. In low phosphorus alloys the eutectic is never visible unless the cooling has been rapid. Alloys with 0.9 per cent P are homogeneous after 2 hours at 690° or 4 hours at 640° C. Cu cooled ex-

tremely slowly may dissolve 13 per cent Sn but in ordinary casting practice only 8 per cent is dissolved and above 8 per cent Sn, Cu₄Sn is present. This forms a binary eutectic with Cu₃P, having the composition Cu, 72; Sn, 25; P, 3, and this eutectic with the alpha solution of tin in copper gives the ternary eutectic having the composition Cu, 81; Sn, 14.2; P, 4.8 and melting at 620° C.

Phosphor-bronzes are classed as: (1) malleable, with less than 6 per cent tin and 0.3 per cent phosphorus or (2) cast (used for bear-
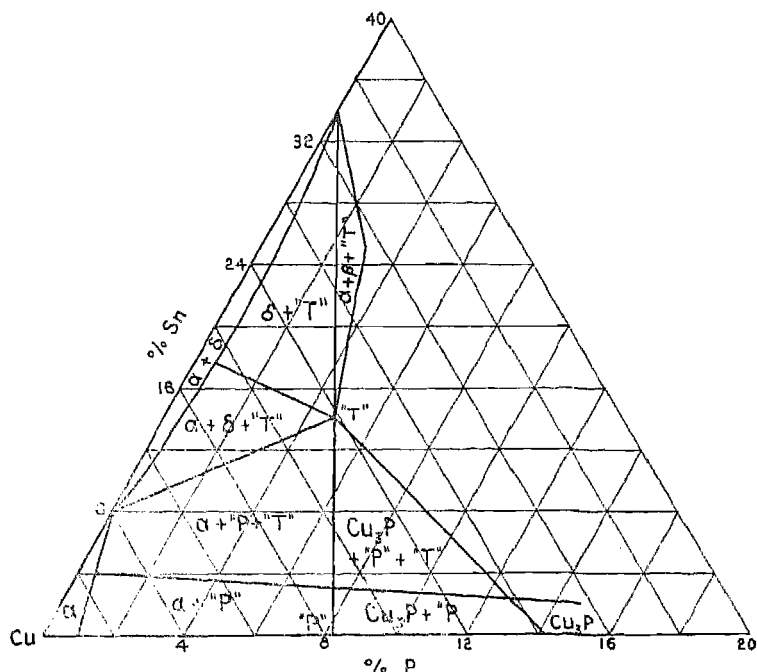
FIG. 2.—Copper-Tin-Phosphorus System, Constitution of Solid Alloys

ings) with less than 12 per cent tin and 1.5 per cent phosphorus. In the case of bearings the hard constituent is the ternary eutectic and sometimes free Cu₃P. The alloys containing lead are the same except for the presence of small globules of lead which act as a lubricant.

Discussion. Several members objected to the authors' conclusions as to the existence of a ternary eutectic.

C. A. Edwards stated that for a ternary eutectic to exist, each of the three binary systems must each possess one, but Cu-Cu₄Sn has none. The point in question might be a ternary non-variant point.

The presence of three constituents might be explained by the deposition from the liquid of Cu_3P and beta, while the latter partly changes into beta in the solid state. The stable alloy would contain Cu_3P and beta.

The authors admitted that Edwards' view is correct and later confirmed it experimentally by annealing one of their alloys and causing the disappearance of the third phase in the so-called ternary eutectic.

W. B. Parker stated that up to 1 per cent Pb, Pb occurred in the eutectic only.

82. **Copper-Tin-Phosphorus** (The Phosphor-Bronzes). Wm. Campbell, *Liddell's Handbook of Non-Ferrous Metallurgy*, New York, McGraw-Hill Book Co., 1926, pp. 41-42.

"The phosphor-bronzes in the wrought form are used for sheet, wire, etc. The castings are somewhat harder and stronger than ordinary bronze and may contain from 2 to 10 per cent Pb (the leaded phosphor-bronzes) in bearings.

"(1) Wrought: 3.5 to 10 per cent Sn, 0.05 to 0.5 per cent P.
(2) Cast: (a) 6.0 to 11 per cent Sn, 0.005 to 0.5 per cent P.
　　　　　(b) 6.0 to 10 per cent Sn, 0.05 to 1 per cent P, 2 to 10 per cent Pb.

The thermal diagram is shown on page 223.

"Copper and Cu_3P (14.2 per cent P) form a eutectic at 8.25 per cent P and 707° C. Copper holds 0.2 per cent P or more in solid solution. In the copper-tin diagram (see Fig. 3) there is a reaction point B at 800° C. and 25.5 per cent Sn ($Alpha$ + liquid → $beta$). Hence in the ternary diagram the Cu-Cu_3P binary line eR must meet the reaction line BR at a reaction point R, which is Cu, 81; Sn, 14.2; P, 4.8 at 610° C., and Rs, the binary $beta$ + Cu_3P, must fall in temperature to s. At R the reaction $alpha$ + liquid → $beta$ + Cu_3P occurs. For example, an alloy x with say, 10 per cent Sn and 0.25 per cent P begins to freeze out dendrites and grains of $alpha$ until the liquid reaches the line BR near the reaction point at y. From y to R the reaction to form $beta$ occurs, while at R this reaction continues and Cu_3P freezes out. The alloy goes solid here and consists of dendrites of $alpha$ with a small amount of a matrix of $beta$ + Cu_3P. At 587° C. $beta$ changes to $gamma$ + $alpha$ and at 520° C. the $gamma$ breaks up into the eutectoid of $alpha$ and Cu_4Sn or $delta$, and the matrix then consists of a mixture of the copper-tin eutectoid and Cu_3P.

"The saturation point of Cu_3P in solid copper has not been accu-

rately determined, but it is over 0.2 per cent. The area of *alpha* alone for castings is approximately *Aa′d′b′*, while for wrought alloys it is *Aadb* because the *alpha* is homogeneous and saturated, whereas in castings it is cored and unsaturated".
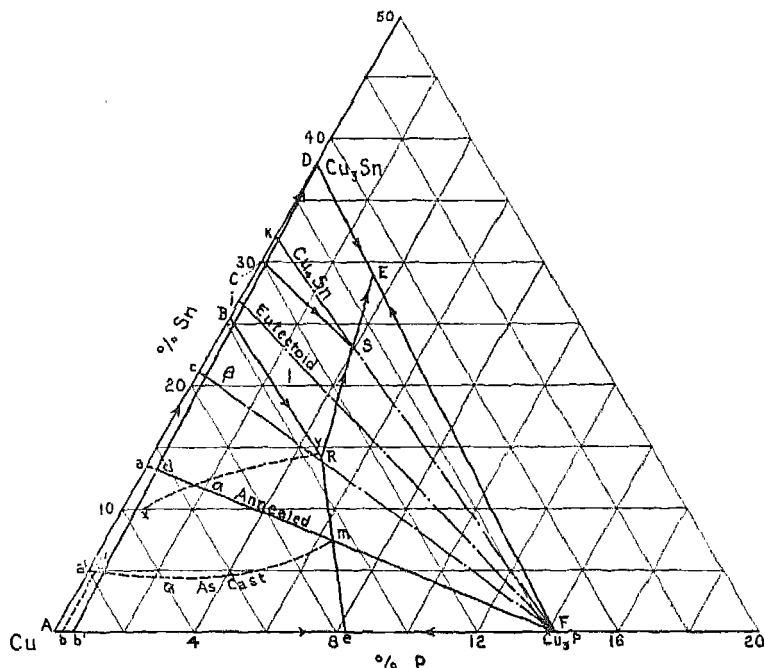
Fio. 3.—Copper-Tin-Phosphorus System, Constitution of Solid Alloys

83. On Lead-Antimony Alloys. W. Gontermann, *Z. anorg. Chem.,* 55:419-425 (1907).

The author investigated the equilibrium of this system by the method of thermal analysis. He tabulated the temperatures of primary crystallization, eutectic temperatures and eutectic durations. Small melts (17-28.5 grams) were used. An atmosphere of hydrogen prevented oxidation. For the microstructure of the alloys of this system he refers to Charpy's work. Strong segregation occurs between 60 and 87 per cent Pb, the primary Sb crystals floating to the top. This segregation cannot be entirely obviated by stirring. Two arrest points with a temperature difference of 4-6° C. were observed at the eutectic temperature.

Matthiessen's electrical conductivity work indicated that Pb and Sb formed an intermetallic compound, but the author found no evidence of such even after leaving the melt at 600-650° C. for a long time (6-11 hours) and cooling to 250° C. in 5 minutes.

The double eutectic point was also observed in an atmosphere of nitrogen. The author explains it as due to the large and small Sb crystals having a different eutectic temperature with Pb.
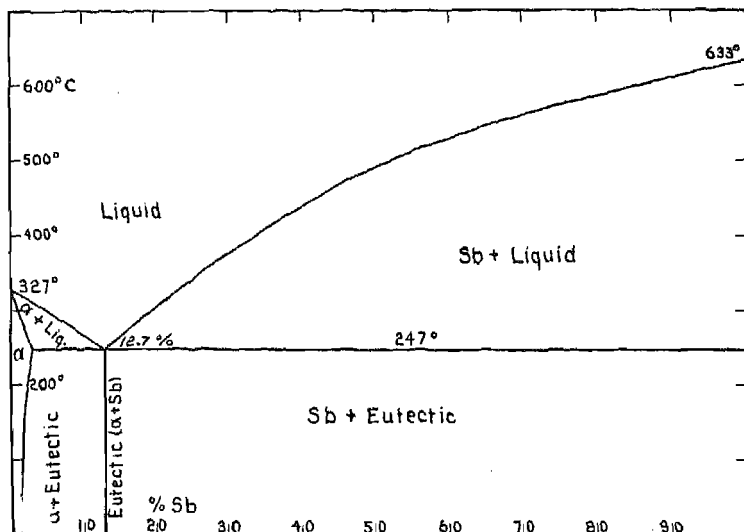
Fig. 4.—Equilibrium Diagram of the Lead-Antimony System

Any solubility of one element in the other could not be detected. Alloys containing only 1 per cent of either element showed the eutectic plainly, confirming the work of Stead. Matthiessen's results must have been due to segregation.

[The electrical conductivity measurements of Dean, Hudson and Fogler indicate that Pb may dissolve about 3 per cent Sb. See *Ind. Eng. Chem.*, 17:1246 (1926).]

84. Contribution to the Constitution Diagram of the System Lead-Barium. J. Czochralski and E. Rassow, Z. *Metallkunde*, 12:337-340 (1920). 7 Photomicrographs.

Thermal and micrographic analyses of Pb-Ba alloys up to 8 per cent Ba were made. The alloys were prepared most conveniently by the use of the alloy Pb, 90; Ba, 10. No solid solutions were formed in

this range but a eutectic is formed of Pb and apparently Pb_3Ba, and containing 4.5 per cent Ba. The eutectic temperature is 282° C.

85. The Binary Alloys of Lead with Lithium up to 2.2 Per Cent Lithium. J. Czochralski and E. Rassow, *Z. Metallkunde*, 19:111-112 (1927). 9 Figures. 1 Table.

The system lead-lithium up to 2.2 per cent lithium is composed of a solid solution of lithium in lead and a compound which apparently has the formula Pb_5Li_2. These form a eutectic which contains 0.65 per cent lithium.

TRANSLATION.

Up to the present there has been no work done on the lead-lithium alloys. It is known that the properties of lead alloys are altered by lithium in a manner similar to that occurring on the addition of sodium. The hardness of the alloys is increased and their properties are altered by ageing. As a rule, very small amounts of the metals in question suffice, usually only a few hundredths of a per cent. The alloys of higher content are of no technological value as they have the unpleasant property of low resistance to corrosion. The investigation, therefore, covers only alloys with low lithium contents.

Thermal as well as micrographical studies were made of the alloys. Pure lead was used in their production. The lithium was introduced in metallic form (98 per cent pure). For a protecting layer a mixture of lithium chloride and potassium chloride in the ratio of 3:2 was used. In the course of the investigation, when the necessity arose of replacing the potassium chloride by a lithium salt, lithium fluoride, because of the great rise in melting point, a reaction occurred between the bath and the protective layer, so that potassium was taken up by the alloy. Cooling curves were taken of a charge of 300 grams of the alloy in a chamotte crucible. In spite of careful alloying and immediate stirring, a lithium loss could not be avoided, especially with high lithium contents. Each alloy, therefore, was analyzed. On adding the lithium a strong reaction occurred at high lithium contents. The temperature sometimes rose more than a 100° C. and a crackling was heard in the melt for quite a long time, probably due to burning hydrogen.

The results of the thermal analysis are given in Figure 1 and in Table 1 of the original paper.

It appears that the solubility of lithium in lead is very small,

between 0.04 and 0.09 per cent. From this lithium content up to 2.1 per cent lithium there is a eutectic at 230° C., the eutectic composition being about 0.65 per cent lithium. At higher lithium contents the temperature of primary crystallization rises rapidly. It reaches 470° C. at 2.15 per cent lithium.

At this composition the eutectic horizontal could still be observed. At higher lithium contents the temperature of primary crystallization increases still more and new arrest points appear, while the eutectic arrest at 230° C. is no longer to be observed. These alloys were not included in the diagram because no unequivocal explanation can be given of the thermal and microstructural phenomena. These alloys, moreover, have no technological importance in view of their high decomposability. It may be mentioned that on freezing of alloys containing more than 5 per cent lithium, shining metallic drops are squeezed from the interior of the alloy out on the surface at a temperature of about 200° C.

The micrographic investigation fully confirms the findings of the thermal analysis. Figures 2-9 of the original article are reproductions of micrographs of lead alloys containing increasing amounts of lithium. At 0.09 per cent lithium (Fig. 3) some eutectic is distinctly visible, but is not noticed below this content of lithium. Fig. 2 shows a specimen containing 0.04 per cent lithium. After a transition stage corresponding to a lithium content of 0.5 per cent (Fig. 4), a pure eutectic is arrived at (Fig. 5) with a lithium content of 0.65 per cent, agreeing with the thermal analysis. Further increase in lithium causes the appearance of a crystal phase which corresponds, in free form, to one of the constituents of the eutectic (Fig. 6 with 0.89 per cent lithium). The proportion of the surface occupied by this constituent increases with increasing lithium content. Figure 7 shows the structure of an alloy containing 1.4 per cent lithium. The eutectic is visible under the microscope up to 2.15 per cent lithium. Above this appears a new constituent as may be seen in Figures 8 and 9.

The production of micrographs presented a few difficulties, as, especially with the alloys of high lithium content, only a few seconds elapsed after preparing the specimen before the surface became worthless due to tarnishing. The finishing polish was made near the photographic apparatus, and the moisture from the polishing medium removed with a cloth wet with a little alcohol. Only in this way could any images be secured.

The observations appear to justify the conclusion that the second

constituent of the eutectic is a compound. The melting curves and the photomicrographs give no evidence of any eutectic above 2.1 per cent lithium. It is to be assumed then, that the composition of the compound lies in the immediate neighborhood of 2.1 per cent lithium. Computation shows that this composition corresponds to the formula Pb_3Li_2. There is then a striking analogy to the lead alkaline earth metal alloys, whose compounds correspond to the formula Pb_3M. It is fairly safe to conclude then, that the compound Pb_3Li_2 occurs in the lead-lithium alloys with low lithium content.

The alloys up to 2.15 per cent lithium are stable even after lying a long time in the air. Alloys with more than 2.15 per cent lithium decompose rapidly in the air.

86. Contribution to the Constitution Diagram of the System Pb-Sr. E. Piworwarsky, *Z. Metallkunde,* 14:300-301 (1922). 2 Photomicrographs.

Incidental to an investigation on Mathesius metal (Pb-Ca-Sr), which he claims is a better bearing metal than either Lurgie or Frary metal, the author has investigated the constitutional diagram of the system Pb-Sr up to 12 per cent Sr.

Sr is practically insoluble in Pb. The melting point rises rapidly at first with increasing Sr content. It reaches a maximum at 12.35 per cent Sr, corresponding to Pb_3Sr at 676° C. The eutectic temperature coincides with the melting point of Pb. The structure is Pb_3Sr crystals in a matrix of Pb.

87. Constitution of the Lead-Base Babbitts. Wm. Campbell, *Liddell's Handbook of Non-Ferrous Metallurgy,* New York, McGraw-Hill Book Co., 1926, pp. 33-34.

The following description of the diagram is quoted:

". . . Within the area *ArOf* antimony is the first solid to separate out of the melt. In the area *fOPd*, crystals of SbSn are the first to form. In the area *BrOPq*, lead freezes out first of all, while in the area *CdPq* the first solid to form is Sn-*alpha*. The line *rO* is the binary Sb-Pb. The line *OP* is the Binary SbSn-Pb, while *Pq* is the binary Sn,*alpha*-Pb. There are two reaction lines. Along *fO* it is Sb + liquid → SbSn. On *dP* it is SbSn + liquid → Sn,*alpha*. At the point of reaction o the reaction Sb + liquid O → SbSn + Pb occurs. At *P* it is SbSn + liquid P → Sn,*alpha* + Pb.

"Due to these reactions, when the alloys are finally solid, only

those within the area *ABg* contain any free antimony, and only those within the area *gBc* contain any free SbSn. In the area *gBof* any antimony that freezes out is used up in the reaction along *fO* or at *O*, while in the area *eBPd* any SbSn that has frozen out is used up by the reaction along *dP* or at *P*.

"The area *ArOf*, in which Sb is the first to freeze is divided into two fields by the line *AO*. Any alloy on the left of *AO* freezes out
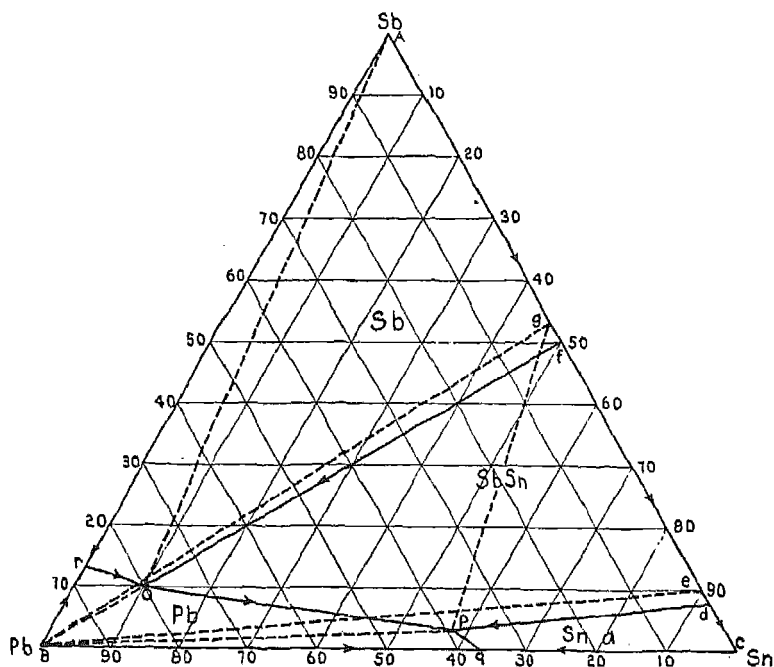
Fig. 5.—Primary Crystallization of Lead-Tin-Antimony Alloys

crystals of Sb and the liquid finally reaches the line *rO*. Here a binary of Sb and Pb freezes out and the liquid finally reaches the composition *O* at 245° C. and Sb 10, Sn 10, and Pb 80 per cent. Here the reaction Sb + liquid *O* → SbSn + Pb occurs and, as the liquid is used up before the Sb, the alloy goes solid here. On the right hand side of *AO*, the Sb in freezing out enriches the liquid in lead and tin until it reaches the line *fO*. Then the reaction Sb +-liquid → SbSn occurs, the liquid changing in composition along *fO* till *O* is reached and the alloy goes solid as before. This is true for all alloys above the line *gB*. For

those lying between *gB* and *fO* the Sb is used up before the liquid and then the alloy acts as if it were in the area where SbSn freezes out.

"Similarly the area of SbSn is divided in two by the line *gP*. Alloys on the left of this line in freezing out SbSn reach the binary line *OP* and follow it as the binary Pb-SbSn freezes out. Those on the right of *gP* finally reach the reaction line *dP* and then the liquid follows *dP* to *P* as *Sn-alpha* forms by reaction. In both cases at *P* there is the reaction SbSn + liquid P → Sn-*alpha* + Pb. Alloys above the line *eB* use up the liquid before the SbSn, and therefore go solid at *P*. Those below this line use up the SbSn in the reaction before all the liquid has gone and continue freezing along the line *Pq* by separating out a binary of Pb and Sn,*alpha*. The point *P* is 189° C. and 2.5 per cent Sb, 40 per cent Pb, 57.5 per cent Sn.

"In the area *dPqC* the first solid to form is Sn,*alpha* and the liquid reaches the line *Pq* and follows it by separating out a binary of Pb and Sn,*alpha*.

"In the field in which Pb freezes out first the liquid may reach *rO,OP* or *Pq* and then freezes as described above".

88. **On the Alloys of Sb with Mn, Cr, Si, and Sn; of Bi with Cr, Si, and of Mn with Sn and Pb. R. S. Williams, *Z. anorg. Chem.*, 55:1-33 (1907). 24 Photomicrographs.**

The author made thermal and micrographic analyses of the system Sb-Sn. He refers to the previous work of Reinders and Gallagher. He regards the heat effect at 310° C. found by the former as an unnecessary complication of the diagram. He finds the (gamma) phase (see equilibrium diagram) to have the composition SbSn.

Sb and Sn are completely miscible in the liquid state and in the solid state form three series of solid solutions, *viz.*, those containing 0.8 per cent, 49.8-52.8 per cent and 90-100 per cent Sb.

The author's diagram is given in Fig. 6.

89. **The Constitution and Structure of Certain Tin-Antimony-Copper Alloys. O. F. Hudson and J. H. Darley, *J. Inst. Metals*, 24:361-371 (1920). 15 Photomicrographs.**

The structure of Sn-Sb-Cu alloys follows. Up to 7 per cent Sb content this is held in solid solution in Sn. Above 7 per cent Sb cubical crystals (*γ*) appear. Cu gives rise to a Cu-Sn constituent which forms a eutectic with the Sb-Sn solid solution. The eutectic contains about 1 per cent Cu. If the Cu content is greater than 1 per cent crystals are

formed. The order of solidification is: ε, γ, eutectic. The ε crystals are feathery, preventing segregation by keeping the γ cubes from rising. Therefore, some Cu is necessary to prevent segregation.

The author describes an investigation of the white metal alloy, Sn, 89.0; Sb, 8.7; Cu, 2.3. The size of the γ cubical crystals depends more on the mold temperature than on the casting temperature. The distribution of the ε crystals depends more on the casting temperature.

The essential condition for a coarse angular structure is undisturbed cooling from a temperature about 50° C. above the solidification
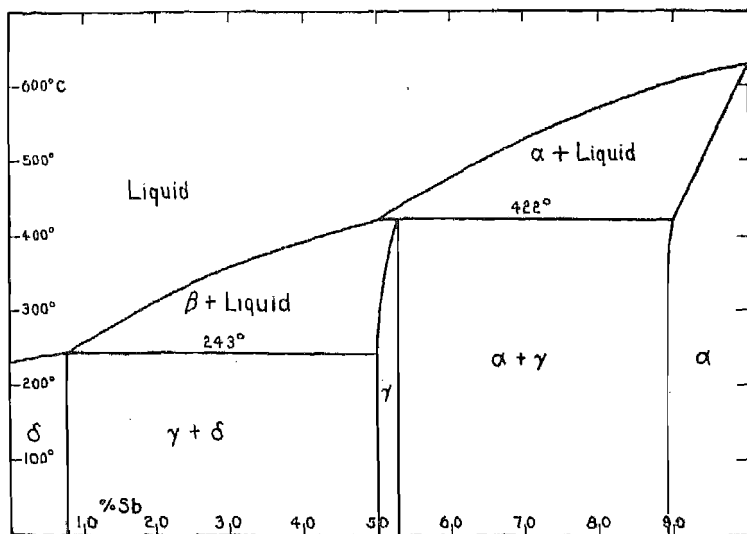
Fig. 6.—Equilibrium Diagram of the Tin-Antimony System

point. The casting temperature should not exceed this. The structure is sensitive to the rate of cooling only near this critical temperature.

90. The Tin-Base Babbitts. Wm. Campbell, *Liddell's Handbook of Non-Ferrous Metallurgy*, New York, McGraw-Hill Book Co., 1926, pp. 35-36.

"Tin containing up to 10 per cent Cu has been used for various purposes. An alloy with 10 per cent Cu is used for bearings. Alloys with lower percentages of copper are used for castings (ornamental) and up to 1 per cent Cu the metal can be fabricated and even rolled out into sheet. The commercial alloys, however, usually contain antimony as well as copper.

"Referring to the right hand side of the copper tin diagram, alloys with more than 8 per cent Cu on reaching the liquidus curve EF begin to freeze out Cu_3Sn, a hard brittle compound. On reaching 415° C. a reaction occurs: Cu_3Sn + liquid F → eta. This eta has been isolated and found to contain about 65 per cent Sn and has therefore been called CuSn. More recent work shows that it contains about 60 per cent Sn and may be Cu_5Sn_4. As the temperature falls, more Cu_5Sn_4 separates out and the liquid changes from F to G. At 225° C. the eutectic freezes as a mixture of Cu_5Sn_4 and tin. In ordinary cooling, however, the reaction at 415° C. is never complete; the Cu_5Sn_4 forms a coating on the crystals of Cu_3Sn and the reaction stops. Alloys with over 8 per cent Cu therefore consist of Cu_3Sn, Cu_5Sn_4, and the eutectic containing 1 per cent Cu.

"The ternary diagram of Sn-Cu-Sb has been worked out for the tin-rich alloys only and is given below. The constituents which first freeze out in the various fields are shown. The line aP is the binary SbSn-eta (Cu_5Sn_4), the line PG the binary of Sn-$alpha$ and Cu_5Sn_4. Fb is the reaction line: Cu_3Sn + liquid → eta or Cu_5Sn_4, while dP is the reaction SbSn + liquid → Sn,$alpha$. At the point P (1 per cent Cu, 7.5 per cent Sb) there is the reaction:

$$\text{SbSn} + \text{liquid P} \longrightarrow \text{Sn-}alpha + \text{Cu}_5\text{Sn}_4$$
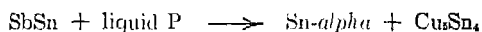
Alloys within the triangle CFb begin to freeze by the formation of platy crystals of Cu_3Sn until the line Fb is reached when the reaction takes place and these platy crystals are soon covered by a layer of eta or Cu_5Sn_4 and the alloys behave as if they belonged to the field $bFGPa$. This latter field is divided into two by a line from P to 40 per cent Cu (Cu_5Sn_4). Above this line solid eta freezes out until the line aP is reached. Here a binary of eta and SbSn freezes out until the liquid has the composition P. Here occurs the reaction between the SbSn and liquid to form Sn-$alpha$ + eta and the alloy goes solid. Alloys below the line also freeze out crystals of eta and the liquid finally reaches the line PG and follows it as the binary Sn-$alpha$-Cu_5Sn_4 freezes. Both of these types of alloys are used for bearings. Britannia metal lies within the field $AdPg$. Sn, $alpha$ freezes out first of all and the liquid reaches the line PG. Then the matrix freezes as a binary of Sn-$alpha$ and Cu_5Sn_4.

"Alloys in the region $BdPa$ begin to solidify by separating out cubes, etc., of SbSn until the liquid reaches aP or dP. In the first case there is a binary of SbSn and eta, in the second a reaction to form

Sn-*alpha*. At *P* there is the same reaction as before. The cubes of SbSn are lighter than the liquid out of which they freeze and tend to segregate toward the top of the alloy. If, however, there is an alloy in the field to the left of the line *aP*, the first crystallization is a network of rods and needles of Cu_5Sn_4, on which the SbSn cubes later form and segregation is more or less prevented".

Fig. 7.—Primary Crystallization of Tin-Antimony-Copper Alloys

91. Micro-chemical Examination of Lead-Antimony, Tin-Antimony, Tin-Arsenic Alloys, Etc. J. E. Stead, *J. Soc. Chem. Ind.*, 16:200-210 (1897).

The author made up 15 alloys of the system Pb-Sb containing from 1-95 per cent Sb. The specimens were polished and etched with dilute nitric acid. Micrographs are given of some of the specimens. Alloys containing over 15 per cent Sb showed cubical crystals. These were isolated by immersing a bar of the 30 per cent Sb alloy in 10 per cent nitric acid for several days. The crystals on the surface became detached and were digested in nitric acid and thoroughly washed.

Analysis showed that they contained only 0.2 per cent Sb. The eutectic alloy contained 12.7 per cent Sb.

The Sn-Sb alloy was treated in the same way. The cubical crystals present, when the Sb content was over 7.5 per cent, were isolated by use of 1:9 nitric acid and analysed. They contained 49.46 per cent Sn, that is, within the limits of experimental error, they had the composition SnSb. A photomicrograph of one of the crystals under a magnification of 200 diameters is given. It is cubical but has two octahedral faces.

92. Segregation Phenomena in Metallic Alloys. O. Bauer and H. Arndt, *Z. Metallkunde*, 13:497-506, 559-564 (1921).

Binary alloys forming a simple eutectic system will segregate if the difference in densities is great and the cooling interval is long. To prevent segregation the alloy should be cooled as rapidly as possible in order to entrap the first separated metal in the crystals of the eutectic and prevent it from rising or falling.

The conditions are quite otherwise in the case of metals forming solid solutions with each other. Experiment has shown that solid solutions are always richer in the constituent of higher melting point than the melt with which they are in equilibrium. The authors trace process of solidification of a mixed crystal system. If the alloy is slowly cooled so that equilibrium conditions are maintained and diffusion has time to act neither mass nor intracrystalline segregation should be present. However, in rapid cooling the crystals on the walls and the nuclei of all crystals should be richer in the constituent of the higher melting point (intracrystalline segregation), which may lead to mass segregation.

The effect of the rate of cooling was confirmed by experiments on several mixed crystal systems in regard to mass segregation and, except in one case (Cu-Mn), in regard to intracrystalline segregation.

Segregation was anomalous in those alloys tending to mass segregation, *i.e.*, in contrary order to that expected from theory. This was attributed to the difference in velocity of crystallization along the different crystalline axes. It was observed most frequently in crystals tending to grow in one direction.

93. Tests on Bearing Metals. H. A. Holz, *Chem. & Met. Eng.*, 27:1061-1062 (1922).

The author recommends standardization of tests on bearing metals. He advocates standard properties: (1) micro-hardness, or micro-

character scale developed by the American Society for Testing Materials; (2) elastic limit in compression; (3) compressive strength (load-diameter curves should be given); (4) melting point (which should be as high as possible); (5) Brinell hardness; (6) bench test (a simple and useful one is that of Professor Kammerer of the Reichsanstalt).

The importance of viscosity has been overrated, the usefulness of the lubricant depends on adhesion to the surface and not on the cohesion of the oil molecules to one another (viscosity).

94. **The Influence of Ratio of Length to Diameter in the Compression Testing of Babbitt Metals.** J. R. Freeman, Jr., and P. F. Brandt, *Proc. Am. Soc. Testing Materials,* 23(2):150-155 (1923).

Compression tests were made on chill cast specimens of tin and lead base babbitts, *viz.,* Sn, 88.7; Sb, 7.9; Cu, 2.7; Pb; Fe . . . Sn, 88.8; Sb, 7; Cu, 3.9; Pb; Fe and Pb, 83; Sb, 15; Sn, 2. Test specimens were 1 in. in diameter and 1, 2, and 3 in. long.

Conclusions: Total deformation increases with the length of time the load is applied, but for loads below an appreciable yield the difference in deformation is negligible whether the load is applied for 30 sec. or 3 min.

For loads up to and beyond those causing appreciable yield the stress deformation curves were the same for all three ratios of length to diameter.

For a 3 in. specimen the unit deformation is the same along the central ½ in. as along the central 2½ in.

95. **A Study of Bearing Metals.** C. H. Bierbaum, *Trans. Am. Inst. Mining Met. Eng.,* 69:972-989 (1923). 8 Photomicrographs, 3 Figures.

All bearing metals are made up of two or more phases, *viz.,* hard crystals which support the load, embedded in a softer and more plastic matrix, which adjusts itself to the shape of the journal and wears down to allow circulation of the lubricant.

Equilibrium conditions do not obtain in ordinary casting practice. Control of the chill effect is of importance, for example, in bronzes where the δ crystals (Cu-Sn eutectic) are desired, excess chill reducing the amount of these, and too slow chilling producing too coarse a structure. The author gives an example of a bronze cast on a carbon

chill which had grains of microscopic size. Due to their different angles of orientation, these wore at different rates and allowed the alloy to act to some extent as a bearing metal.

Bierbaum disparages accelerated wear tests. Almost all such tests favor the softer or more easily run in metal. Tests of such metals on a hardened steel shaft are meaningless. They should be tested against the same metal as is used in service. He claims that in service, the bearing surfaces must polish one another, to insure the best results. The hardness of the hardest particles of the journal and bearing should be the same. Polishing and not an abrading action is desirable.

The worn-off particles carried away by the oil from new bearings are large at first but decrease in size later, finally becoming ultra-microscopic for bearings of correct design.

It is obvious that a knowledge of the physical properties and abrasion hardness of the different micro-constituents of both bearing alloy and shaft is imperative.

The author describes a new instrument, the "Microcharacter", for measuring the hardness of the individual grains of a metal. It consists essentially of an artificial white sapphire (fused alumina) ground to a cubical point which is much finer than that of the finest cambric needle and much harder than that of any constituent discovered in alloys (tin oxide). The instrument may be mounted on the stage of a microscope. The jewel is mounted on a spring suspension, allowing a constant pressure to be exerted on the point. The width of the cut made is measured by a micrometer eyepiece. The author gives 6 photo-micrographs (2000 x) of cuts made by the instrument.

A scale of microhardness (k) is proposed in terms of the width of the cut (λ), *viz.*,

$$k = \lambda^{-2}(10^4)$$

The microhardness of the grains in most metals varies in different directions. Heat tinting or very light etching may be used for the identification of the constituents.

By this instrument it is clearly shown that the addition of Zn above 2 per cent to a bronze increases the hardness of the soft crystals, thus reducing the range of hardness, and therefore the value of the alloy as a bearing metal. This is strikingly confirmed by practice, as an increase of Zn is known to increase destructive wearing. The author gives table of the microhardness of various metallic constituents. He also brings out the fact that the $SnCu_4$ crystals in a babbitt may be harder than any crystals of a machine steel.

Discussion. H. S. Rawdon mentioned that at the Bureau of Standards, similar hardness measurements were made, using a steel safety razor blade, and showed 2 photomicrographs, comparing the two methods.

96. **Effect of Duration of Load in Hardness Testing of Metals.** (Bearing Metals.) P. Lieber, *Z. Metallkunde,* 16:128-131 (1924).

A study was made of the effect of duration of loading on the ball-hardness of Regel, Einheits, Lurgi, Calcium, and CMA bearings metals (all white metals). The last three contain alkaline earth metals.

The load was applied by a testing machine. In the first series the diameter of the hole was measured, but to obtain comparable results the ball had to be reinserted in the same hole after each measurement, which, however, was objectionable due to friction between the ball and the walls of the hole.

In the second series the depth of penetration was measured by the use of a Martens' mirror.

Results: (1) Ball hardness is greatest at the start, it decreases rapidly at first and then more slowly. The decrease in hardness is greatest for the first two of the above metals. (2) The hardness of Regel, Lurgi, and calcium metals is still decreasing after 20 min. Further experiments are necessary to determine if this attains a constant value. (3) Similar experiments made on Cu and Fe showed an initial decrease in hardness, but a nearly constant value was soon reached. (4) In practice one-half min. is sufficient for Cu and Fe, but 3 min., if not more, is necessary for the softer metals.

Tables and curves of hardness number against duration of loading are given. A comparison of diameter and depth measurements shows that in soft metals the ball raises a ridge around the hole, but that in Cu and Fe the edge of the hole is depressed as in the case of iron floating on mercury.

97. **Report of Microhardness.** Sub-Committee V of Committee E-4 of the American Society of Testing Materials, H. S. Rawdon, Chairman, *Proc. Am. Soc. Testing Materials,* 26(1):572-580 (1926).

This report concerns tests made with the Bierbaum microcharacter on various metals and under various conditions. (For a description of this instrument, see Abstract 95.)

In view of the fact that different observers moved the cutting point of this instrument across a specimen at different speeds, an investigation was made of the effect of wide variations in cutting speed (36 to 480 revolutions per min. of micrometer feed). The effect on the mean of a series of readings was small, the variation in the width of individual cuts being greater than that due to alteration of speed. However, speed is not a negligible factor in the testing of heterogeneous alloys, as the point tends to dodge around the harder particles. A slow uniform speed is, therefore, of importance in using this instrument.

Tests were made on similar materials by observers using different instruments, and by different observers using the same instrument. The results were very variable, but more consistent results were obtained with the harder materials.

These tests complete the program outlined by the sub-committee. The conclusions reached were as follows:

"1. The method, obviously, in its present form is not capable of much accuracy. The differences in the results reported by different observers using the same instrument with the same specimens ranged from 10 to 50 per cent. For useful comparisons, the average of at least ten readings should be taken.

"2. In measuring the width of the cut made by the point, it is recommended that the 'fringe' of distorted metal usually found on each side of the cut be disregarded. The width of the cut may be measured directly with a suitable scale after projecting the image on the ground glass screen of the microscope at a known magnification or a properly calibrated micrometer ocular may be used.

"3. The test is not suitable for revealing the work hardness of cold rolled metals. A pronounced difference in hardness as shown by Brinell hardness tests of a metal after varying degrees of cold rolling resulted in only a slight change in the hardness as determined by the scratch method.

"4. In spite of these difficulties, the method is very useful in showing differences in the hardness of the different constituents of a heterogeneous material and is the only available method for this purpose".

98. Study of Bearing Metals and Methods of Testing. T. D. Lynch, *Proc. Am. Soc. Testing Materials,* 13:699-713 (1913).

Tests carried out at the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., on a well-known friction testing

machine were not conclusive and could not be duplicated from day to day or even on the same sample. Dudley was convinced that only a service test could be relied on.

Some electric motors operating under severe service conditions with tin base babbitt linings in cast iron shells were refitted with lead base babbitt in place of the tin base. The life of the bearings was increased. Accordingly lead base was substituted for tin base babbitt. Trouble, however, was soon experienced in the testing laboratory. Some of the soft bearings were brittle and others wiped out.

Tests were made of lead base bearings in a motor with an eccentrically loaded shaft, but the motor frame failed before the bearing. The Brinell hardness tests failed to distinguish between toughness and brittleness.

An impact fatigue test was then devised which showed the quality of the babbitt more clearly and definitely than any other quick test. If the alloy is soft it peens out, if brittle it breaks, if both it peens out and crumbles. The test represents the most severe service conditions exclusive of wiping.

Two test machines are illustrated, one light, and the other with a 1¾ ft. lb. drop hammer. A great variety of tests were made on these machines, showing that melting and pouring temperatures must be kept within narrow limits. The tin base metals showed much less variation. Curves of thickness *vs.* number of blows and illustrations of the tested samples are given. The temperature control was found to be so important that automatic regulators, holding the temperature to plus or minus 10° C. were installed on each babbitt pot. The author's conclusions were:

(1) The number of compositions should be as small as possible.

(2) The constituent metals should be of superior grade, carefully tested and inspected.

(3) The alloying must be done so that metals of high and low melting point are alloyed far below the melting point of some of their component parts (500° C. has been found suitable for babbitt). The melt should be kept covered with powdered charcoal.

(4) Pouring babbitt too cold tends to produce a granular or coarsely crystalline form, and pouring too hot tends to produce a softening effect. The lead base metals are not nearly so foolproof as the tin base ones, and the range of pouring temperatures is more limited. A pouring temperature of 460° C. has given excellent results for both lead and tin base babbitt.

(5) Preheating the molds to 100-150° C. tends to prevent blow-holes and similar defects, and also the shrinking of the liner away from the shell.

(6) A babbitted bearing must not be jarred until nearly solid, since any disturbance at this time tends to enlarge the crystals and cause brittleness.

(7) The matrix of the lining should be just hard enough to support the hard crystals under load. The latter should be as numerous as possible, without touching and causing brittleness.

(8) Brinell hardnesses of 23.5 for lead base and 30 for tin base alloys have been found to give excellent results.

99. Note on the Wear of Bronzes. A. Portevin and E. Nusbaumer, *Trans. Am. Foundrymen's Assoc.,* 21:517-529 (1913). (Reprint.)

Tests were made of some sand castings of bronzes made of very pure materials. The apparatus used was the Derihon mill. In this the specimen bears on the circumference of a polished steel wheel which turns at a high speed in an oil bath. A lever presses the specimen against the wheel with a known force, and the wear is indicated by the motion of the lever.

The conditions of the tests are: speed = 3200 revolutions per min., total number of revolutions = 2,000,000, total distance = 2000 km., oil is "Autol", used for high speed auto gears. (Constants of this are given.)

The results of the tests are given in the form of curves.

The authors' conclusions are, that under these special conditions:

(1) The wear of ordinary bronzes is proportional to the Sn content or more exactly to the amount of the delta phase present.

(2) The introduction of P decreases the rate of wear of high Sn bronzes and increases that of low Sn bronzes.

(3) When a bronze is bearing against a polished steel journal, even under abundant lubrication, there may be produced a skin of cold worked metal on the surface, which does not suffer more than a little wear. When this skin is worn through, wear suddenly becomes extremely rapid.

(4) The tendency to recrystallize on annealing, which is favored by the effect of cold work, is found in bronzes as well as in steels and seems to be a phenomenon of extremely general character.

100. A New Method of Wear Testing. A Wear Testing Machine.
     L. Jannin, *Rev. Métal*, 19:109-116 (1922).

A description is given for a new wear testing machine, devised by the author. A rapidly rotating trunnion makes an impression on a strip of metal, and this is compared with the impression made on a standard metal under the same conditions of speed and load. The effect of hardness and polish of the trunnion was investigated.

Jannin concludes that: (1) the principal cause of wear of the bearings is lack of polish of the journal; (2) the principal cause of wear of the journal is impurity of oil.

101. Some Abrasion Tests Made on M. Jannin's Wear Test Machine. L. Guillet, *Rev. Métal*, 19:117-119 (1922).

The effect was studied of polish, material and speed of rotation of the trunnion on different alloys, including: Cu, 64; Pb, 30; Sn, 5; Ni, 1 and Hoyt's antifriction metal: Sn, 92; Sb, 5; Cu, 2.5; Ni, 0.5. The method is rapid and gives comparable results.

102. Study of Jannin's Method for Wear Testing of Metals, and Its Application to Antifriction Metals. P. Nicolau, *Rev. Métal*, 21:347-355 (1924).

Nicolau has built a machine similar to the wear testing machine of Jannin and has made tests on 17 antifriction metals of different degrees of hardness. Jannin's own conclusions that the condition of lubrication and speed of test have little effect on wear seem to show quite clearly that the impressions are not characteristic of wear, besides contradicting experience. In two series of tests Nicolau tried to determine what part of the impression was due to static load and how much to actual abrasion.

The static tests were made both by the Brinell method and by static impression of the shaft on the specimen.

The actual wear was determined by measuring the loss of weight after 57 tests of 15 min. each, and a relation is given between volume of metal removed and width of impression. A practically linear relation exists between the diameter of impression in the wear test and the static hardness.

In a 15 min. test the metal removed by abrasion was one-fifth the volume of the impression or one-half the volume of the static impression. The proportion would be still less in a 2 min. test.

A third effect is due to vibration of the shaft which tends to enlarge the impression by impact.

The above analysis explains the conclusion in regard to the abrasion and speed effect arrived at by Jannin and Guillet. He mentions the work of Portevin *et als.* with abrasive paper, in which no relation was found between wear and hardness.

Nicolau states that his conclusions apply only to white metals, as the relative amounts of effect due to static load, abrasion and vibration might be different for bronzes. In any case the determination of a quantity from measurements of the 4th root of that quantity are inaccurate.

103. A Note on Capt. Nicolau's Wear Tests. M. L. Jannin, *Rev. Metal*, 21:356-357 (1924).

This article is a reply to Nicolau's criticisms on Jannin's method of making abrasion tests (see Abstract No. 100). Nicolau's test conditions are different from those recommended by Jannin. Nicolau used a polished shaft which greatly reduces the abrasion. It is evident that with a perfectly polished shaft abrasion would be reduced to nothing (*cf.*, however, Abstract No. 215), and no distinction between the wear resistance of different metals could be made.

In any case the results of this method are only relative and not absolute. For testing bronzes and white metals, Jannin recommends a shaft finished with Norton's No. 60 emery, and not polished. The tests should also be made on flat strips and not on cylinders. A pressure of only 10 kg. should be used (Nicolau used 20 kg.). To reduce the impact of vibrations, the inertia of the rotating parts should be small. (Nicolau used a lathe.)

Jannin points out that part of the wear of white metal is due to a dragging action (wiping), which is sometimes great enough to cover the oil grooves of a bearing.

The real conclusion to be drawn from Nicolau's tests is that the abrasion of a perfectly polished shaft on white metal is practically zero.

104. Some Experiments on the Abrasion of Metals. K. Honda and R. Yamada, *Sci. Rept. Tohôku Imp. Univ.*, 14:63-83 (1925).

Tests were made of the abrasion of a cast iron disk in various states of polish on different metals. Emery wheels of varying degrees of roughness were also used instead of the cast iron. For the soft metals

the relative coefficient of abrasion (grams lost per horse-power) corresponded generally to the degree of brittleness of these metals, being 0.67 for Cu and 14.73 for Bi. The abrasion of carbon steels was also measured.

The amount of wear is proportional to the frictional horse-power if the coefficient of friction is constant.

With constant frictional horse-power the amount of wear increases with the coefficient of friction.

The effect of the velocity of abrasion on the amount of wear is negligibly small.

105. The Wear of Cast Iron by Sliding Friction. O. H. Lehmann, *Giess. Ztg.*, 23:597-600, 623-627, 654-656 (1927). (Abstract in *Mech. World*, 82:428; 1927.)

"The aim of the author's investigations was to discover how far the wearing qualities of the metal are dependent upon its chemical composition and physical properties. The experiments were carried out on an apparatus, rigidly fixed, in which the test piece, shaped as a brake block and provided with thermometer pockets, is fitted to a lever between the fixed fulcrum and the adjustable weight, and is brought into contact with a disk 4⅜ in. diameter and 1¼ in. wide, with a peripheral speed of 7.54 ft. per sec. running under a load of 114 lb. per sq. in. Disks were made from rail steel, hard cast iron of 203 Brinell units and soft cast iron of 152 Brinell units. The test pieces were made from various engine parts and were tested with each of the three disks; the results were tabulated according to the chemical composition and hardness of the specimens, which ranged from 110 to 190 Brinell units. The weight lost after a definite period (two hours) under test was noted and plotted as a curve. From examination of this evidence the author suggests that neither hardness nor chemical composition alone accounts for the wearing qualities, which he attributes mainly to a pearlitic structure, as revealed by the most resistant specimens. The latter indicate that metals of similar hardness or similar composition behave differently according to their structure. In the case of steel on cast iron, the presence of a phosphide eutectic acts adversely, whereas this is not found to be the case with iron on iron. The author concludes that the finely divided graphite in the pearlitic surfaces is a principal factor in resisting wear. A bibliography of the literature on the subject is given".

106. Thermal Conductivity of Some Industrial Alloys. H. M. Williams and V. W. Bihlman, *Trans. Am. Inst. Mining Met. Eng.*, 69:1065-1069 (1923).

The thermal conductivities of seven Society of Automotive Engineers bearing metals were determined.

Conductivity of alloys having a large per cent of Cu is two or three times that of Sn and Pb base alloys.

(See Table 16.)

107. Thermal Conductivities of Industrial Non-Ferrous Alloys. J. W. Donaldson, *J. Inst. Metals*, 34:43-56 (1925).

(1) Industrial non-ferrous alloys in cast condition have relatively low thermal conductivity compared with copper ($K = 0.067$ for Monel metal to $K = 0.242$ for 70:30 brass).*

(2) Thermal conductivity increases with the temperature.

(3) Cu-Sn alloys have lower thermal conductivity than Cu-Zn alloys.

(4) Ni has a detrimental effect on the thermal conductivity.

Phosphor bronze: $K = 0.129$ at 95° C. and 0.174 at 400° C.*

Sn base bearing metal: $K = 0.07$ at 76° C. and 0.09 at 167° C.

108. On the Specific Heats of Pb-Sb Alloys. R. Durrer, *Phys. Z.*, 19:86-88 (1918).

According to Tammann the specific heat of a simple eutectic system with no solid solutions should be a linear function of the concentrations.

Durrer determined the specific heat of alloys of the system Pb-Sb by the method of mixtures. The alloys were prepared by melting the metals together in a glass tube in an atmosphere of nitrogen. He determined the equilibrium diagram of this system, his points lying slightly above those of Gontermann's.

He found the specific heat to vary linearly with the concentration within the experimental error.

$$c = 0.04965 - 0.0001884 \text{ (per cent Pb)}$$

109. Fluidity Tests of White-Metal Bearing Alloys. E. R. Darby, *Proc. Am. Soc. Testing Materials*, 26(1):186-193 (1926).

The viscosity of substances such as oils, where specific gravities are comparatively constant, may be determined through measurement

* K in cal. per cm.² per sec. (°C. per cm.).

of the time of flow of a given volume at a standard head through a standard orifice. With materials of widely varying specific gravities as obtains with alloys, this method would bring in the effect of different pressure heads, even if the lineal head were maintained the same. In some experiments at the author's plant it was found that the distance of flow into a small channel in an iron mold, while indicative of pouring temperature for a given alloy, gave no comparative values with metals of widely varying specific gravity.

The author has devised an apparatus which allows the rate of flow to be measured under a constant difference of gravity head, rather than lineal head. It consists essentially of a vertical glass tube with an orifice at its lower end, which is plunged below the surface of the molten metal. Paraffin placed inside the tube serves to keep the surface of the metal therein clean. The tube is closed at its upper end and is connected to an air pump and a manometer. This latter is read when the surface of the metal in the tube makes contact with an electrode therein, and again when the air pressure is raised by a definite amount. For details, the original paper should be consulted.

The alloys tested were the twelve American Society of Testing Materials standard white metals, but work only on Nos. 1, 2, 3, 5, 9, and 12 has been completed. Analysis showed that the percentage of the major constituents remained within 0.1 per cent of the specified amounts and the amounts of allowable impurities did not exceed 0.02 per cent each.

Curves are given showing: time of flow vs. temperature; rate of flow vs. temperature; and temperature vs. time cooling curves. These curves show that the lead-base alloys maintain their fluidity almost down to their freezing points, while the tin-base ones lose it 100°-150° C. above. The tin-base alloys refused to flow through a 1 mm. orifice at 350°-425° C. and the flow was uncertain even with a 2 mm. orifice. A new apparatus using a larger head is to be built.

Some of the changes in the flow curves have no corresponding changes in the cooling curves. Separation of a solid constituent may either decrease or increase the viscosity provided the quantity is not sufficient to obstruct the orifice.

The proper pouring temperatures given for these alloys in the American Society of Testing Materials specifications were compared with the temperatures of maximum fluidity as given by these tests. The pouring temperature given for No. 1 (441° C.) coincided exactly with the point of maximum fluidity, that of No. 2 (424° C.) is within

20° of the point of maximum fluidity, and that for No. 3 (491° C.) was at the point of maximum fluidity. The pouring temperature given for No. 5 was 366° C., but experiments preliminary to the fluidity tests indicated that the alloy would froth badly unless poured around 525° C., so that the machined surfaces of bearings cast of this would show pinholes. This alloy ceased to flow in the tube at 425° C. and the curve shows that 500° C. is the lowest permissible pouring temperature. The experience of the Chicago Bearing Metal Company has shown that the addition of only a few tenths of a per cent of copper to such an alloy as Pb; Sb, 9-11; Sn, 6-8 will cause it to froth on pouring at any temperature below 482° C. Most of the copper may be removed from such an alloy by sweating.

The pouring temperatures given for Nos. 9 and 12 corresponded fairly well with those selected from the fluidity curves, but 375° C. would seem to be better than 332° C. for No. 9, and 329° C. for No. 12.

The author's conclusions were as follows:

"1. The difference in specific gravity of the solid metals influences their relative fluidities in the molten state.

"2. The lead-base alloys have a more evenly sustained fluidity above their melting points.

"3. The separation of the Cu-Sn or Cu-Sb compounds affects the fluidity of the melt by obstruction. (This is proved by experiments with 2 mm. orifices.)

"4. There is no conclusive evidence of a viscosity change with temperature as exists in oils and other liquids such as molten slags".

110. **Test Bars to Establish the Fluidity Qualities of Cast Iron.** (Some non-ferrous metals included.) C. Curry, *Trans. Am. Foundrymen's Assoc.*, 35:289-306 (1927).

The author defines fluidity (*coulabilité*, in the original French) or running quality (life) to be the aptitude of a liquid in a given condition to fill a mold prepared under determined conditions. It depends not only on the properties of the liquid metal but also on the materials and dimensions of the mold, as well as the temperature both of the metal and the mold.

The author describes the test bars used in various earlier fluidity experiments. He first used a spiral test bar with roughly triangular cross-section, the plane of the spiral being horizontal with apex of the triangular cross-section down. This apex was rounded and there

was a round elevation on the opposite side (top) of the triangle. The mold was gated at the outer end of the spiral and the metal thus flowed inwards around the spiral.

It was found that the results were greatly affected by slight burrs (fins) or even by a slight dropping of sand at the gate of the core. Therefore the tap hole was as exactly dimensioned as possible. It is essential that the mold be horizontal. Variations of humidity have little effect, neither have trapped gases at the end of the spiral.

This test bar was later modified by omitting the projection on top of the cross-section and by gating at the inner end of the spiral.

The surface of the mold had a great effect on the length of casting obtainable with a given head of metal. Much longer castings were obtained when the surface of the mold was coated with graphite than with the natural sand surface.

The author gives the results of some tests made on non-ferrous metals and alloys by Thibault in the following table. In this series of tests a larger pouring basin was used.

Fluidity Qualities of Some Non-Ferrous Metals.

Composition Per Cent							Test Bar Length, Divisions
Cu	Sn	Zn	Pb	Ni	Fe	Si	
99.5	...	...	...	...	...	...	6*
93.0	0.85	1.15	0.75	...	0.25	...	9†
92.95	0.65	0.85	...	...	...	1.45	11‡
93.0	...	1.50	...	1.42	...	...	11§
90.0	8.0	2.0	...	...	...	...	14
90.0	7.5	1.0	1.5	0.05	0.25	...	18
86.0	14.0	...	...	...	...	...	16
85.0	13.0	1.22	0.08	0.20	0.10	...	21
86.0	12.0	1.88	...	0.04	...	...	18
77.0	8.0	...	15.0	...	...	...	14
76.5	7.5	...	14.5	1.0	0.5	...	16
88.0	12.0	...	...	...	...	...	12
86.16	10.96	1.35	1.92	Tr.	0.03	...	17
90.0	10.0	...	...	...	...	...	10
89.94	9.63	...	0.17	0.06	0.01	...	12

* Metal completely oxidized.

† Metal sound; the spiral is carried back to starting line; it breaks if the tests of malleability are continued: this is the indication of the presence of tin and zinc.

‡ If the running qualities have been increased, this fact is indicated by break-ing the test bar in the hot condition; the pieces are very malleable when in the cold condition.

§ Has not increased running qualities nor is the malleability increased, the assumed percentage of copper doing away with the effect of zinc.

An interesting point was an examination of copper to determine the best deoxidizer for this metal, one which would improve the poor

running qualities as well as improve its mechanical strength. Zinc, manganese, nickel, phosphorus, aluminum, magnesium, and silicon increase the running qualities. Silicon, magnesium and aluminum caused the test bars to break on removing from the mold, therefore the best deoxidizing agents are manganese, phosphorus, and nickel. The latter gives good results only if added as 50 per cent zinc-nickel. The bar length of 65:35 brass was increased from 8 divisions to 12 divisions by spraying the inside of the mold with a naphtha residue or with linseed oil.

111. Shrinkage of the Lead-Antimony and of the Aluminum-Zinc Alloys during and after Solidification. D. Ewen and T. Turner, *J. Inst. Metals*, 4:128-162 (1910).

The metals used were 99.95 per cent Pb and 99.5 per cent Sb. Bars were cast in sand molds one-half in. sq. They were too rapidly cooled to obtain satisfactory cooling curves. As far as could be judged the piping was largest when the casting temperature was nearest to the solidification temperature. The authors found that Sb expanded on solidification, confirming the work of Murray but contradicting that of Wüst. The first reading of the extensometer was taken when the gate was full of metal. The maximum shrinkage at 50 per cent Sb may be explained by an altered method of crystallization, the neighboring compositions which had a coarser structure being cast at a higher temperature.

Type metals and bearing metals are included in the range, 15-25 per cent Sb. The alloys at the lower part of this range may be expected to give the sharpest castings. While the expansion diminishes from a maximum at 15 per cent Sb to a minimum at 30 per cent Sb, the hardness increases rapidly through this range. An alloy with 20 per cent Sb gives a good combination of these properties.

Sb Per Cent	Expansion (in./ft.)	Remarks
0.0	0.0000	Not piped.
5.1	.0011	
14.6	.0012	
23.2	.0006	
37.2	.0000	
48.8	.0015	
57.1	.0000	
68.4	.0019	Gate slightly piped.
77.5	.0020	Much piped gate.
87.7	.0020	Gate slightly piped.
100.0	.0025	

112. Volume Changes in Alloys of Copper with Tin. J. L. Haughton, *J. Inst. Metals*, 6:192-221 (1911).

The author cites the work of previous investigators in determining the equilibrium diagram of this system, which is still imperfectly known, and the work of Wüst and Ewen on volume changes.

In this research the author used very pure electrolytic copper and the purest obtainable tin. These were melted in a covered pot and cast at a high enough temperature so that the mold was completely filled before solidification took place. The specimens were T-shaped bars, three-quarters in. sq.

The composition varies from pure copper to pure tin in steps of 5 per cent. Curves of the volume change are shown for the series of alloys. In addition to the expansion on solidification, most of the alloys showed a change in the rate of contraction on cooling which appeared usually to coincide with some phase change as shown by the equilibrium diagram. A graph is given showing both expansion during solidification and crystallization-interval plotted against the percentage of tin. (Murray found that in the brasses, expansion was directly proportional to the crystallization-interval.) The expansion curve for Cu-Sn has five maxima. Of these, only the ones at 10, 46, and 65 per cent Sn coincide with the maxima in the crystallization-interval curve. The peak at 30 per cent Sn, Murray attributes to the existence of Cu_4Sn, but the author does not agree with this. He has no explanation of this point. The peak at 65 per cent seems to coincide with the composition of CuSn, but it is doubtful if this exists as the expansion coincides well with the crystallization-interval here. There is no *a priori* reason why a compound should expand more than a solid solution. In fact, the reverse would be expected. This is borne out by the fully verified compound Cu_3Sn which falls at the minimum of the expansion curve (40 per cent Sn).

The most pronounced expansion is that which coincides with the solidification of the eutectic at the tin-rich end of the system. (Eutectic temperature $= 220°$ C.) Another volume change of considerable interest is that occurring at 500° C. where *alpha + beta* changes to *alpha + delta*. The range of this is from 15 to 25 per cent Sn, and the change lasts from 540 to 480° C. It was not possible to get accurate determinations on the Cu rich alloys owing to blowholes.

Scleroscope tests were made on this system and a high maximum at 30 per cent Sn was found, corresponding with one in the expansion curve. It is almost impossible to find any agreement between the

observation and the theory of Kurnakoff and Schemtschuschny. The application of the theory is rather difficult, however, owing to the complicated nature of the castings and of determining just what their state is.

Discussion: C. H. Desch criticized the method used by the author as measuring the expansion of only the outer shell of crystals. He cited the work of Turner, who found no expansion on solidification by this method of Bi which is known to expand by 3 per cent of its volume. He explained readings of instrument as due to the thrust of crystal skeletons in the direction of their axes.

Turner in reply stated that the expansions were real and agreed with those found by Keep and Wüst with a different apparatus. He explained the results obtained on Bi by the fact that maximum expansion occurs before solidification, as in the case of water.

113. The Shrinkage of Metals. F. Johnson, *Proc. Inst. Brit. Foundry-men,* 16:235-252 (1922/1923). *Foundry Trade J.,* 27:393-396 (1923).

The author criticizes the confusion regarding definition of the terms "shrinkage" and "contraction". The metal shrinks in volume in three distinct stages: (1) liquid shrinkage (contraction), (2) solidification shrinkage, (3) solid shrinkage. Shrinkage is uniform in (1) and (3), but in (2) conditions are very different and the rate of shrinkage is usually far greater due to the difference in density of the liquid and solid.

Therefore the amount by which the metal fails to fill an open mold will be a function of the pouring temperature. It does not follow, however, that the linear contraction is a function of the pouring temperature as the outer crust formed must always be of the same dimensions, the hydrostatic pressure keeping the metal against the walls until it freezes.

Very few data exist on shrinkage during freezing and these are correct only for special conditions. The author shows two curves for the shrinkage of the system Cu-Zn which differ in some places by 100 per cent.

Gates are always necessary; the design should be such that the minimum of internal stress is produced.

The author mentions the work of Wüst, who found that alloys consisting of aggregates as Pb-Sb shrunk less than the constituents, while solid solutions such as brass shrunk more. Haughton supposes

that a compound should show a minimum expansion. This is confirmed by Murray for Cu_2Zn_3. The constitution and the shrinkage may be greatly changed by small additions.

The work of Edwards and Gammon on the light Al-Cu alloys is mentioned. The relative proportion of solid and liquid can be determined from the equilibrium diagram and the density ascertained. For instance, in the Al-Cu system the crystals first formed sink in the liquid; the later ones rise. Hence the necessity of bottom gating in some alloys due to the bridging over of the metal in the gate. The author describes an apparatus for determining linear shrinkage.

114. The Use of Molybdenum for the Improvement of Aluminum Alloys. H. Riemann, *Z. Metallkunde*, 14:195-203 (1922).

Among other tests, some Al alloys containing Mo were tested as bearings in a Hanffstengel machine. These alloys contained in addition to not more than 1 per cent Mo, not more than 6 per cent of Mg, 3 per cent of Cu or 3 per cent of Ni.

At 210 revolutions per min. under a load of 100 kg, the Mo alloys endured only 5-12 min. against 17 min. for normal bronze and 30 min. for white metal. There is a slight improvement as the Mo and Cu contents increase. Specimens of the same alloy differ by 50 per cent due to segregation. This is confirmation of the experience that Al is not adapted for the matrix of a bearing metal, although these alloys generally had the structure requisite for a bearing metal, *viz.*, hard crystals in a softer matrix. However, this structure alone does not seem to be all that is necessary for a bearing metal.

115. Studies on the Effect of the More Important Metallic and Non-Metallic Additions to Normal Copper-Tin Bronzes. H. von Miller, *Metallurgie*, 9:63-71 (1912).

The author used apparatus similar to Wüst's for determining shrinkage. The ends of the solidifying specimen are rigidly connected to pistons fitting in cylinders filled with water. The volume change is determined from readings of the level of water in capillary tubes connecting with the cylinders.

The alloys were poured at uniform high temperatures into molds preheated to 250° C.

Most of the alloys tested expand upon solidifying, and the volume does not become less than the original volume until the second arrest point is reached. Cooling curves, and curves of volume *vs.* temperature

are given. Values of shrinkage, expansion and tensile strength are given in tables. (See Table 14.)

116. Effect of Changes in Composition of Alloys Used by American Railroads for Car Journal Bearings. G. H. Clamer, *J. Am. Inst. Metals*, 9:241-263 (1915).

Clamer gives the car journal specifications for 36 different railroads. He tabulates his own results for density, hardness, and tensile properties of 27 different bearing metals, including the following ranges of composition: Cu 65-90 per cent, Sn 5-10 per cent, Pb 0-30 per cent, Zn 0-15 per cent. He also gives transverse tests on bearings made of 18 different metals. He refers to wear tests and results of his own wear tests are given.

Clamer's conclusions are: (1) alloys for car bearings should contain at least 65 per cent Cu; (2) there should be a proper balancing of the four metals used; (3) it is not desirable to have over about 5 per cent Sn in car journal bearings; (4) it is desirable to increase Pb in the alloy rather than Zn, and with increasing Pb, Zn should be diminished; (5) alloys containing 5 per cent Sn, less than 20 per cent Pb, and less than 5 per cent Zn should be entirely satisfactory for all classes of car journal bearings.

117. The Effect of Lead on Red Brass. J. Czochralski, *Z. Metallkunde*, 13:171-176 (1921). 9 Photomicrographs.

This paper discusses an investigation of the effect of addition of lead to red brass (Cu, 86; Sn, 9; Zn, 5). Addition of Pb was made at the expense of all three constituents. Castings were made both in green sand and preheated molds. Hardness and torsional strength are almost unaffected by the addition of Pb up to 6 per cent. Tensile strength was lowered somewhat in three series of tests and increased in one. In two series the impact fatigue endurance was decreased, in another increased. Non-uniformity of behavior was due to casting defects. Lead tends to concentrate in nodules, thus weakening the alloy. This can be avoided by careful stirring at a sufficiently high temperature.

Structure: sand casting, α solid solution and $(\alpha + \gamma)$ eutectic; chill casting, similar but much finer dendritic structure. Pb is not evident in the micros up to 6-8 per cent Pb. Annealing above and below 480° C. and quenching from 700° C. had little effect on the structure. Pb is therefore assumed to be in solid solution up to 6-8 per cent Pb.

Photomicrographs of alloys containing 10-20 per cent Pb showed marked segregation of this metal. Area measurement, however, showed about 8 per cent to be still in solid solution.

Lead is an advantage in founding red brass. The metal does not have to be heated to so high a temperature and the molten alloy is more fluid. Lead increases the machinability.

118. Babbitt Metal. L. D. Allen, *Machinery*, 29:114-115 (1922).

Loads on no type of bearing should exceed 2500 pounds per sq. in. A semi-tin or semi-lead alloy is most suitable for loads up to 1800 pounds per sq. in. (The thinner the liner the higher the tin and copper content required.) Such an alloy has better antifrictional properties than genuine babbitt (80-90 per cent tin). No single bearing metal is most suitable for all conditions.

The author presents a résumé of the effect of different constituents:

Tin toughens the alloy, lowers the melting point, but is somewhat lacking in anti-frictional properties. Under heavy friction, tin tends to heat quickly and to fuse.

Lead softens the alloy, it is more antifrictional than any other metal.

Copper hardens and toughens the alloy and raises the melting point. It increases friction slightly, and is not very desirable in babbitt.

Antimony hardens the alloy, raises the melting point and reduces friction. It is imperative that the antimony should be completely reduced and evenly distributed, otherwise very hard spots develop.

Bismuth reduces friction, lowers the melting point and prevents shrinkage. Not largely used on account of expense.

Aluminum is rarely used except as a deoxidizer. It toughens the alloy but increases friction.

Certain combinations of tin, copper and antimony shrink considerably on cooling, although each component alone shrinks but slightly.

119. The Effect of Small Quantities of Nickel upon a High Grade Bearing Metal. A. H. Mundey and C. C. Bissett, *J. Inst. Metals*, 30:115-120 (1923).

Nickel up to 0.5 per cent was added to a reliable bearing alloy, Sn, 93; Sb, 3.5; Cu, 3.5, also 1 per cent Ni to Sn, 92.5; Sb, 3.5; Cu, 4. The alloys were poured at 350° C. into molds at 100° C. The tensile and compression tests do not compare favorably with those on the original alloys, although there is a slight increase in the Brinell hard-

ness. The compression tests were especially disappointing. The alloys with nickel gave way completely under 22,000 pounds per sq. in. as against 32,000 pounds per sq. in. for the original alloys.

Running tests on the Thurston machine were satisfactory.

120. Nickel in Brass and White Metal. W. M. Corse, *Metal Ind. (N. Y.),* 22:234-235 (1924). (A lecture delivered before the Metropolitan Brass Founders Association, May 14, 1924.)

The addition of 0.05 to 1.5 per cent Ni increases the density of alloys containing upwards of 80 per cent Cu to a remarkable extent. Density increases proportionately to the Ni content up to 1.5 per cent Ni, but there is no increase from 1.5-5.5 per cent; from 5.5-10 per cent the structure is again improved.

If the hardness is to be kept constant, the tin content must be lowered as the Ni content increases.

The Cu-Sn-Pb type of bearing bronzes are noticeably improved by the addition of 0.25-3.5 per cent Ni. This is particularly true of "heavy duty" bearings such as are used for rolling mills. The tensile strength and the elongation of a 80-10-10 bronze when modified to contain 1 per cent Ni will be improved 10-30 per cent in most instances. The resistance to compression and shock is improved without impairing the plasticity.

Ni increases the rate of cooling, reducing segregation to a minimum.

121. Notes on the Composition of Antifriction Metals. A. L. W., *Mech. World,* 82:23 (1927).

One advantage of plain bearings lined with antifriction metal is that they fail slowly instead of instantaneously, giving time to shut off the power before disastrous results occur. The structure of the typical bearing metal is described, *i.e.,* hard particles in a softer matrix. The effect of different components of white bearing alloys are given as follows:

Tin. High tin alloys wear well and withstand high bearing pressures without undue flow of the metal.

Copper. If more than 7 per cent of this metal is present, the alloy is likely to be brittle and not suitable for high speed machinery. When copper is present, it is advisable to quench after casting, as this increases its resistance to wear.

Antimony. This metal hardens white metals and should not be used where temperatures are much above normal, as it gradually wastes away under these conditions, leaving minute pinholes.

Lead. Not over 1 per cent of this metal should be present. Within this limit it increases the ability of the alloy to adjust itself to the shaft.

Bismuth. In the author's experience its only function is to improve the casting qualities.

Zinc. This should never be present in a bearing alloy as, like copper, it causes brittleness, but without simultaneous increase in strength.

Nickel. This metal is beneficial if added in small amounts, but its use is not likely to be popular.

Iron. This is said to have a bad effect, but is rarely met with.

122. Some Experiments on the Effect of Sulfur on Copper. E. S. Sperry, *Brass World*, 9:91-93 (1913).

Sulfur in copper and its alloys is cumulative, where it may be absorbed from the fuel, *i.e.*, the sulfur content increases in successive remeltings, leading to some of the prejudice against scrap metal. The author made some experiments to determine the permissible amount of sulfur in copper. His conclusions are:

(1) Copper will not absorb more than 1 per cent of sulfur; if more is added it will separate out as cuprous sulfide.

(2) Sulfur causes blowholes in copper.

(3) Sulfur renders copper red-short.

(4) Sulfur when present in a considerable quantity produces a crystalline fracture.

123. The Influence of Sulfur on the Properties of Non-Ferrous Metals. Anonymous, *Metal Ind. (London)*, 29:349 (1926). (Note.)

"Sulfur has a marked effect on the mechanical properties of non-ferrous alloys. W. Meigen and R. Stock-Schroer made experiments in this direction with some copper-base alloys, the composition of which is recorded in the table below. The test figures show that a sulfur content of less than 1 per cent reduces the tensile strength as much as 70.0 per cent."

Composition of Some Copper-Base Alloys.

	Copper	Red Brass	Bronze	Tombac
Cu	90.14	91.98	93.92	95.76
Zn	.....	0.42	3.29	0.87
Sn	.....	3.97	0.84	1.83
Pb	.....	2.78	1.18	0.54
S	0.86	0.81	0.70	1.00
Tensile strength, pounds per square inch	8,000	28,000	17,500	16,500
Same, without sulfur........	23,000–28,500	30,000	28,500	28,500
Per cent decrease due to sulfur	70.0	5.2	39.3	42.0

124. Note on a Curious Change in the Microstructure of White Metal Produced by Traces of Zinc. L. Archbutt, *J. Inst. Metals*, 7:266-268 (1912).

A white metal used by the Midland Railroad, *viz.*, Sn, 84.2; Sb, 10.5; Cu, 5.3 usually had a reddish tinge, but occasionally some samples were obtained which were dead white. One of these, of old remelted white metal, had the composition: Sn, 81.02; Sb, 11.05; Cu, 7.22; Pb, 1.30; Zn, 0.032; Fe, 0.034. Photomicrographs showed that the usual Sb cubes had a ruptured appearance. When 0.1 per cent Zn was added, the effect became still more marked, and the color of the ingot changed. The cubes tended to arrange themselves in starlike groups. Photomicrographs are shown of specimens from four experimental ingots containing 0, 0.1, 0.1, and 0.2 per cent Zn. In the last the SnSb was partly in the form of small grains throughout the alloy.

125. How Arsenic Affects Alloys. H. J. Roast and C. F. Pascoe, *Foundry*, 51:67-70 (1923).

The effect of adding 0.8 per cent and 1.4 per cent As to a Pb-Sb alloy was studied. The arsenical alloys maintain their hardness better as the temperature rises and also have by far the finest grain, having hard crystals in a softer but tough matrix. These alloys run more readily at 700° F. (370° C.) than any of the other alloys tested, and oxidize less. They cost less than the high tin alloys.

126. Effect of Impurities on the Compressive Strength and Brinell Hardness of Babbitt Metal at Normal and Elevated Temperatures. J. R. Freeman, Jr., and P. F. Brandt, *Proc. Am. Soc. Testing Materials*, 24(1):253-257 (1924).

A study of the effect of additions of small amounts of As, Cu, and Zn to a typical lead base and a typical tin base babbitt with respect

to the Brinell hardness and the yield point in compression (reduction in length $=$ ⅛ per cent).

Addition of As up to 0.46 per cent to the lead base alloy (Pb, 73.8; Sb, 16.7; Sn, 9.3) caused an increase in Brinell hardness number of less than 7 per cent at 20° C. and about 13 per cent at 100° C., while the effect on the yield point was irregular, although 0.46 per cent As caused an increase of about 15 per cent at 20° C. The increase in Brinell hardness number and yield point were of the same order of magnitude for additions of Cu up to 1.1 per cent and of Zn up to 1.4 per cent, except that 1.4 per cent Zn caused an increase of 20 per cent in yield point at 100° C.

Addition of As up to 0.5 per cent to the tin base alloy (Sn, 90.4; Sb, 4.6; Cu, 4.6; Pb, 0.3) caused increase of like magnitude, while little further increase of yield point was caused by addition of As up to 3 per cent. The effect of Zn up to 1.3 per cent was to decrease the Brinell hardness number about 10 per cent and increase the yield point by a small amount at 20° C. and by about 30 per cent at 100° C.

127. Segregation and Grain Growth of Crystals of Bearing Metals. E. G. Mahin and J. F. Brocker, *Proc. Indiana Acad. Sci.*, 1919, pp. 91-97. [From *Chem. Abstracts*, 16:548 (1922).] Photomicrographs.

This is a description of one phase of an investigation of segregation and grain growth in babbitts. The alloy used was Sn, 85.7; Sb, 9.86; Cu, 3.34; Zn, 0.70; Pb, 0.40. This was melted at 650° F. (343° C.) and cast into iron molds and then heated to temperatures from 160°-550° F. (71°-288° C.) and either chilled or slowly cooled after periods from 1.5 to 5 hours. Appreciable grain growth and segregation occurs at temperatures as low as 225° F. (107° C.) and progresses with increase of temperature and length of time heated.

The low temperature limit above is practically at the lower limit of the epsilon Sn-Cu range, near the lower bound of the gamma Sn-Sb range and well below the liquidus of both binary systems. The practical melting and casting of babbitts is done at higher temperatures than these, thus offering greater opportunity for crystal growth and segregation.

128. Observations on a Typical Bearing Metal. H. E. Fry and W. Rosenhain, *J. Inst. Metals*, 22:217-239 (1919).

Apart from composition and microstructure, the physical properties of a bearing metal must vary widely with the widely varying con-

ditions of preparation. A preliminary study of the effect of various factors was made on a typical alloy, *viz.*, Sn, 87; Sb, 9; Cu, 4 approximately.

Both sand and chill castings were made. (3 in. $\times$ ½ in. sq.) Sand castings were poured at 300°, 400°, and 600° C. into molds, cold and at 60° C. The mold temperature has little effect. In each case there was a greater number of large crystals at the top. The coarseness of the crystals increases with the pouring temperature. A temperature of 300° C. (below the liquidus) is just too low to produce a uniform structure.

Chill castings poured at 300° C. and 400° C. show fine-grained structure which is more uniform at 400° C. The tendency of the cuboid crystals to concentrate at the top is absent in the chill castings. If the mold is cold or warmed to only 100° C. there is a very definite chilled border. Raising the pouring temperature from 300° to 400° C. increases the width of this. If the mold temperature is 200° C. and the pouring temperature is 350° C. the structure is uniform and fine-grained throughout. A table of depth of chill for all the chill castings is given. A table of Brinell hardness numbers for all ingots is given. The variations in Brinell hardness numbers are rather small, but the chill cast are generally harder than the sand cast.

The effect of hammering was investigated. (It is common practice to peen marine bearings.) Hammering actually decreased the hardness, except in one case where it increased it slightly. The coarsely crystalline ingots cracked and broke. The cuboid and Cu-Sn crystals were broken by this treatment. (Illustrated by photomicrographs.) Subsequent annealing caused a further decrease in the Brinell hardness number.

Discussion: R. T. Rolfe showed six photomicrographs of Sn, 85; Sb, 8.5; Cu, 6.5 whose structure is similar to that of Fry and Rosenhain's alloy. He gives the variation of Brinell and scleroscope hardness tests over an ingot. Chill cast ingots are harder in the middle (34 *vs.* 31). These ingots showed a coarser structure due to slower cooling. He mentioned the theory of Behrens and Bausch. Experiments by the company which employed him showed that the best size for the Sn-Sb cuboids was 0.05 mm. (W. H. Allen & Son, Bedford, Eng.)

F. C. Thompson pointed out that the ground mass of Fry and Rosenhain's and of Rolfe's alloys show a duplex structure.

Rosenhain in replying to one criticism mentioned that one of the forces on a bearing metal in service is a tangential pull due to the

viscosity of the oil. Otherwise there would be no wear until the oil film had broken down. He had the impression that the oil film dragged out particles, particularly of the softer constituents, and thus eroded the alloy.

Fry and Rosenhain gave heating and cooling curves for their alloy. Further experiments confirmed the work of Z. Jeffries on the Brinell hardness number. If the Brinell test was made by leaving the load on a short time (30 sec.) the cold-hammered metal was softer than the cast. The reverse was true if the load was removed immediately after application. They agree with Jeffries that hardness in this case is a question of viscosity of the metal in the amorphous state. Their alloy did not contract on solidification. Annealing removed coring in the ground mass.

129. Rate of Cooling Determines Hardness of Alloy. L. Kaul, *Automotive Ind.*, 50:723 (1924). (From *Allgem. Automobil. Ztg.*)

The rate of cooling rather than the pouring temperature determines the hardness of ternary bearing alloys. Sn-Sb-Cu alloys give large Sn-Sb cubes if poured at 930° F. (500° C.) and smaller if poured at 750° F. (400° C.). Higher pouring temperatures break up the molecular aggregates, and if carried far enough this may proceed even to individual molecules. Due to this they are able to rearrange themselves on slow cooling and give large cubes. Slow cooling from a low pouring temperature never does this. The author cites an Italian experiment in confirmation of this point. Copper, owing to its high melting point, remains in the state of paired molecules long after the tin and antimony. The author gives a theory of the molecular structure of the elements lead, antimony, and bismuth based on their physical properties and on their microstructure.

130. Influence of Pouring Temperature and Mould Temperature on Properties of a Lead Base Antifriction Alloy. O. W. Ellis, *J. Inst. Metals*, 34:301-322 (1925).

Preliminary Investigation.

Compression tests were made on the alloys Pb, 85; Sb, 10; Sn, 5 . . . Pb, 80; Sb, 15; Sn, 5, and Pb, 80; Sb, 15; Sn, 36; Cu, 1.5, with the following results:

(1) The replacement of Pb by Sb increases the resistance to compression (likewise the hardness, *cf. J. Inst. Metals*, 19:151 (1918).)

(2) The replacement of Sn by Cu increases the resistance to compression but the Brinell hardness is little increased.

(3) Mold temperatures have a greater effect on the mechanical properties than the pouring temperature.

Investigation of the Alloy Pb, 83.1; Sb, 12.1; Sn, 4.8.

The structure is a matrix of Pb-Sb eutectic containing cubes of the compound SnSb and it is signally affected by variations of the factors associated with pouring.

Samples were poured at temperatures from 300° C. to 500° C. into iron molds at 0° C., 100° C., and 200° C. It was found that:

(1) For a given mold temperature, an increase in the pouring temperature increases the size of the SnSb cubes and coarsens the matrix.

(2) An increase in pouring temperature has less effect on segregation than an increase in mold temperature. (Marked segregation occurs only in the case of the highest mold temperature.)

(3) Mold temperature has a greater effect on hardness than pouring temperature; increase in mold temperature reduces the resistance to slowly applied stresses.

Investigation of the Alloy Pb, 82.5; Sb, 11.0; Sn, 5.5; Cu, 1.0.

No investigation of the mechanical properties was made, but from micrographic and thermal investigation there was found:

(1) A pronounced effect on the microstructure caused by Cu.

(2) An almost complete elimination of segregation due to Cu.

(3) Evidence for an intermetallic reaction at 334° C.

131. **The Influence of Pouring Temperature and Mould Temperature on the Properties of a Lead-Base Antifriction Alloy.** O. W. Ellis, *Univ. Toronto—School Eng. Research—Bull. No.* 6:143-164 (1926). (31 Figures. 1 Table.)

PRELIMINARY INVESTIGATION.

In a preliminary investigation tests were made on three lead-base alloys, *viz.*, Pb, 85; Sb, 10; Sn, 5;—Pb, 80; Sb, 15; Sn, 5;—and Pb, 80; Sb, 15; Sn, 3.5; Cu, 1.5. Only the compression tests were of especial interest and the following conclusions were drawn from these:

"1. The replacement of lead by antimony increases the resistance of these alloys to compression. It may be added that the replacement of lead by antimony was also found to increase the hardness (Brinell). *Cf. J. Inst of Metals,* 19:151 (1918). (See Abstract No. 49.)

"2. The replacement of tin by copper increases the resistance of these alloys to compression. The Brinell hardness, however, is scarcely affected by this substitution.

"3. Mold temperatures exert a more powerful effect on the mechanical properties than do pouring temperatures".

INVESTIGATION OF LEAD-BASE BEARING METAL FREE FROM COPPER.

The alloy Pb, 83.1; Sb, 12.1; Sn, 4.8 was chosen for this investigation because it appeared to the author to have the best all around mechanical properties. It consists of a matrix of lead-antimony eutectic containing cubes of the compound SnSb. The structure of each of these constituents was signally affected by variations in the casting conditions.

Ingots 2 in. long by 1.5 in. diameter at the top and 1 in. diameter at the bottom were cast of this alloy in duplicate steel molds. Five pouring temperatures (from 300°-500° C.) and three mold temperatures (from 0°-200° C.) were used.

The time was recorded when the mold was filled and again when the casting was quite solid. In certain castings whose times of cooling were comparatively long, observation was made both of the time taken to reach the liquidus (255° C.) and the solidus (245° C. = eutectic).

Micrographs were made of specimens taken from the top, middle, and bottom of each casting. Marked segregation was observed only in castings which had been poured into molds at 200° C., therefore, except for these, the results for the alloys given in Table 1 of the original paper can be looked upon as representative of the casting as a whole.

The results of the work were summarized as follows:

"1. . . . for a given temperature of the mold, increase in pouring temperature results in an increase in the size of the 'gamma' cubes and in a coarsening of the matrix of the alloy.

"2. Increase in pouring temperature has less effect on segregation than increase in mold temperature.

"3. Mold temperature has a greater effect on the hardness and compressive strength of this alloy than has pouring temperature, increase in mold temperature reducing the resistance of the alloy to slowly applied stresses".

It is difficult to state the above conclusions in terms of cooling or freezing rates, the measurement of which was crude. The attempt to

correlate the size of the *gamma* cubes or the coarseness of the matrix with the cooling times was not completely successful. The time of cooling of the sample poured at 500° C. into the mold at 0° C. was quite appreciably less than that of the sample poured at 300° C. into the mold at 100° C., but, contrary to expectation, the *gamma* cubes were larger in the first alloy. (The author states that he may be incorrect in assuming that the reciprocals of the cooling times measure rates of cooling.) Undercooling may have some effect here.

The results agree with those of Hudson and Darley on tin-base alloys.

INVESTIGATION OF A LEAD-BASE ALLOY CONTAINING COPPER

The effect was investigated of the addition of copper (to prevent segregation) to an alloy similar to the one above. The alloy as made up had the composition: Pb, 82.5; Sb, 11.0; Sn, 5.5; Cu, 1.0.

Castings were poured at 300°, 400°, and 500° C. into molds at 0°, 100°, and 200° C. The mechanical properties were not investigated. The results of the micrographic examinations were so surprising that the author was led to study the electrical resistivity in the liquid state.

Copper almost completely eliminated segregation, not, however, by entanglement of the *gamma* cubes by Cu_3Sn needles as was the case in some other lead-base bearing metals; but in some castings poured at 300° C. by an effect as yet undetermined by the author, and in case of castings poured at 400° and 500° C. by a complete change in structure, *i.e.*, replacement of the *gamma* cubes by needles of the compound Cu_2Sb, "Regulus of Venus". (The author states that the effect at 300° C. may be related in some way to that of copper in transforming the *gamma* cubes, as referred to below.)

In castings poured at 300° C., the *gamma* cubes became larger and the matrix coarser with increase in mold temperature. Needles of the purple compound Cu_2Sb were not entirely absent although relatively few in number.

In castings poured at 400° C. few cubes were found, in fact they were rare except in castings poured into molds at 200° C., which cooled somewhat more slowly than the others. The cubes were replaced chiefly by the needles of Cu_2Sb, which were quite unaffected by mold temperature. This, however, affected the eutectic.

Castings poured at 500° C. had a structure similar to those poured at 400° C., but the eutectic was more affected by mold temperature and the purple needles were more uniform in size and distribution.

Only in castings poured into molds at 200° C. were the *gamma* cubes numerous enough to be noticeable.

These results were so surprising that the author felt that some error must have occurred, such as segregation in the ladle. The results were shown to be correct, however, if the casting which had been poured at 300° C. into the mold at 200° C. was remelted and heated to 500° C. and poured into a mold at room temperature. The *gamma* cubes were practically all replaced by the purple compound.

In another test some of the alloy was heated to 500° C., slowly cooled to 300° C. and poured into a mold at room temperature. The resulting structure was a compromise between the two types.

The author explains these phenomena by the occurrence of an intermetallic reaction in the liquid alloy between 300° and 400° C., which may be expressed by the equation: $2\,Cu + SnSb = Cu_2Sb + Sn$.

The existence of the compound Cu_2Sb in the liquid state was demonstrated by Bornemann, but no evidence of the existence of *gamma* in the liquid state has ever been found. If it does exist and reacts with copper according to the above equation, the resistivity would be expected to change.

The author made resistivity measurements and gives his results in the form of graphs, though he does not give absolute values of resistivity. A radical change is seen to occur in the alloy at 334° C., *i.e.*, in the liquid alloy, a change of the above character in the opinion of the author. Copper may react with SnSb or directly with antimony to form Cu_2Sb, but there is no clear reason for doubting the former possibility (existence of SnSb in the liquid state). A cooling curve of the alloy also shows a distinct heat effect at 334° C.

In a lead-base alloy containing copper, small needles of Cu_2Sb were evident and the *gamma* cubes had a web-like structure, which the author believes due to the copper. He believes that this effect may have some indirect connection with the influence of copper in controlling and preventing segregation.

132. Age-Hardening of Lead-Tin and Lead-Antimony Alloys.
    (Part of Chairman's Address, Birmingham Local Section of the Institute of Metals.) H. W. Brownsdon, *J. Inst. Metals*, 26:397-398 (1921).

Brownsdon gives curves showing change in the impact hardness on ageing up to 67 weeks of Pb-Sn (up to 4 per cent Sn) and Pb-Sb (up to 4 per cent Sb). Pb-Sb becomes harder during the first week and

then gradually softer, while the Pb-Sn alloys become soft somewhat rapidly at first and then more gradually. No comparison can be made with the usual measures of hardness. These measurements were obtained by letting a weight fall on a cylinder of the alloy and noting the permanent deformation.

133. On the Relation between the Equilibrium Diagram and Hardness in Binary Alloys. T. Isihara, *Sci. Rept. Tohôku Imp. Univ.*, 11:207-222 (1922).

From scleroscope determinations on several binary systems, Isihara derives the following conclusions: (1) In a series of binary alloys forming solid solutions in all proportions the effect of quenching on the hardness is small. The hardness of either metal is increased by adding the other, the maximum hardness being for an alloy having equal atomic percentages of each, as stated by Tammann, and Kurnakow and Zemczuzeny. (2) Quenching has little effect on the hardness of solid solutions. (3) If the quenching temperature lies above a eutectoid point or a solubility line, the hardness of the quenched specimen shows a discontinuity in at least the direction of the hardness curve changes. (4) The hardness of an annealed eutectoid alloy is a maximum with respect to concentration. (5) In alloys containing a eutectoid constituent an ageing effect occurs after quenching, though it is usually small. (6) In the system Cu-Al (Al bronzes) quenching from a temperature above the eutectoid point softens the alloy. This is directly contrary to the interference theory as applied to solid solutions. (7) There is a very intimate relation between hardness and the equilibrium diagram, so that ambiguous points of the latter may be determined by hardness measurements.

Cu-Sn alloys quenched from 700° C. give an upward cusp at the composition Cu, 75; Sn, 25.

134. The Hardness of Metals as Affected by Temperature. K. Ito, *Sci. Rept. Tohôku Imp. Univ.*, 12:137-148 (1923).

Brinell hardness tests were made at temperatures between —50° C. and 150° C. on a number of metals, among them a babbitt: Sn, 88.8; Sb, 7.4; Cu, 3.7; and a bronze: Cu, 79.7; Sn, 17.7; Zn, 2.1. The load used on the babbitt was 500 kg. and on the bronze 1000 kg.

For babbitt, the Brinell hardness number = 52 at —49°, 31.5 at 18°, 10.8 at 145° C.

For bronze, the Brinell hardness number = 159 at —42°, 144 at 17°, 116 at 143° C.

A linear relation exists between the *logarithm* of the Brinell hardness number and $t°$ C.

135. How Dull Tools Displace the Grain of Bearing Metals. C. H. Bierbaum, *Am. Machinist*, 47:665-667 (1917).

The author describes the operating conditions of bearings (no contact between metals, relation of oil film thickness to load, speed, etc.) and the requisite structure for a bearing metal, *viz.*, hard particles in a plastic matrix.

The hard particles should not be harder than the journal, for example the hard Cu_4Sn crystals in a pure tin bronze will score a machine steel shaft. However, if lead is added, somewhat different results are obtained, as particles of this metal locate themselves in close proximity to the hard crystals, thus allowing them to adjust themselves to new positions according to the bearing requirements. The hard particles, due to wearing, will stand out in relief, allowing the lubricant to circulate between them.

It is common knowledge that cold rolled or cold drawn material is not suitable for bearings. The reason is apparent from the metallographic point of view. The metal is compressed, and the crystal structure changes, leaving the hard particles with little or no freedom to adjust themselves. Except in the case of a few alloys, the same effect is produced by machining with a blunt tool. The author gives photomicrographs of a bronze worm wheel cut with a dull hob and a bronze bush cut with a dull broach, both showing distortion of the grain. For comparison he shows a photomicrograph of a bronze showing no grain distortion even after a heavy cut, with a sharp tool.

136. The "Weathering" of a Lead and Sodium Alloy. Anonymous, *Brass World*, 2:26 (1906).

As would be expected, Pb-Na alloys oxidize on exposure to the air. An illustration is given of a cake of Pb, 98.5; Na, 1.5 which had remained in comparatively dry air for about two months, when it started to grow "fuzz". The growth had the appearance of a fungus and the branches extended one-quarter inch above the surface. It appeared to consist of sodium carbonate. The formation took place more rapidly where slight cracks existed, although finally the whole surface became covered.

137. Note on a Failure of "Manganese-Bronze". J. H. S. Dickenson, *J. Inst. Metals,* 24:315-332 (1920).

The author investigated the failure of the end plate of a turbo-alternator rotor. Several of the peripheral projections holding the damping bars broke, the fracture being that characteristic of strongly overheated or burnt alloy steels and without visible distortion.

The alloy was cast Mn-Bronze, Cu, 55.75; Zn, 36.77; Mn, 3.87; Al, 2.56; Fe, 1.30; Sn, 0.08; Pb, 0.07. It was a typical beta brass of polyhedral structure. The appearance of solder on the surface, the whitish tinge of the fracture and the evidence of intergranular films indicated that the weakening of the metal occurred during the original soldering or in service. Evidence indicated that overheating occurred in service and the solder penetrated between the grains of the bronze, while it was under stress, thus producing brittleness. Pieces of such a bronze gave a good bend test with a tough fibrous fracture, at 20 and 200° C., yet if touched with a piece of solder on the tension side while under small load at 200° C., they instantly collapsed. The solder had to melt on contact, however. No effect was obtained on the compression side. Similar tests were made on other bronzes and brasses, stress-strain curves being given.

On the whole the tendency of fluid alloys was to penetrate *via* the grain boundaries both in *alpha* and *beta* brass. The only apparent reason why polyhedral *beta* brasses fail more easily is the absence of intergranular locking.

138. The Penetration of Brass by Tin and Solder. (With a Few Notes on the Copper-Tin Equilibrium Diagram.) H. J. Miller, *J. Inst. of Metals,* 37:183-192 (1927). 14 Figures. 9 Tables.

Summary and Conclusions:

"1. The cracking of brass articles upon immersion in molten tin or solder presents a close similarity to the phenomenon of 'season-cracking' and the penetration of mercury between the grain boundaries of brass.

"2. The cracks, as a rule, follow an inter-crystalline path, but occasionally they cut through a crystal.

"3. The cracking is primarily due to the presence of stress, either of an internal or an external nature. No cases of cracking have been experienced when it was known that stress was entirely absent.

"4. Tensile experiments have shown that the amount of stress necessary for brass to crack in molten tin or solder is much higher

than that required for cracking to occur in mercury. The temperature
of the molten metal has some influence.

"5. Industrial articles which crack in molten solder must be in a
state of great internal stress, so great that there would be serious
liability of them cracking in subsequent service".

To overcome liability of cracking during tinning and soldering of
brass it is recommended that the articles should be free from an
injurious amount of stress, attainable by care in the cold working or
by low-temperature annealing.

An intermetallic compound was observed in brass test pieces that
had been penetrated by tin. This observation led to some work on
the tin end of the copper-tin equilibrium diagram. The author found
solubility limits of copper in tin much different from those found by
Heycock and Neville and still more different from those of some other
investigators. His results are as follows:

Temperature (°C.)	240	290	335	385	420
Solubility (Per Cent Cu)	0.90	1.65	3.00	6.05	7.90

In another test, use was made of the fact that the compound CuSn
is heavier than tin. If an alloy containing a little copper is maintained
at a temperature below the liquidus for a long time, CuSn sinks and
the upper parts of the liquid should be of equilibrium composition.
The results found were nearer to those given above for solubility than
to those of Heycock and Neville.

Temperature (°C.)	227	285	340
Solubility (Per Cent Cu)	0.70	1.83	3.45

Micrographic examination showed that the eutectic point lies be-
tween 0.6 ad 0.7 per cent Cu, instead of at 1 per cent Cu as found by
Heycock and Neville or still higher by other investigators.

Discussion. (Joint discussion on papers by H. J. Miller, H. J.
Hartley, and R. Genders, pp. 223-240.)

Sir Gerard A. Muntz suggested that Miller would have obtained
the same results by heating and straining only, in the absence of tin
and lead. That is to say, solder gets into the brass because it was
cracked already, not because the cracks were made by the molten
metal. This phenomenon is connected with the brittle range (block
breaking point) of brass from 170° to 350° C.

H. J. Hartley asked if Miller verified the composition of the compound which he stated to be CuSn. He himself found a product which suggested an alloy of Cu_5Zn_8 and Cu_4Sn.

U. R. Evans suggested that mercury penetrates more rapidly than solder due to its greater volatility, the metal distilling inwards.

A. Pinkerton has examined large numbers of failures which occurred when tin and solder were applied to stressed brass, but could find no evidence that penetration occurred elsewhere than at a crack. He was therefore inclined to the view that the failure is due not to the molten metal but to "fire-cracking". Further examination, however, showed that in some cases penetration occurred even where no cracks were visible. In some cases cracking seemed to be connected with a slight over-annealing or large crystal grains.

Miller in reply stated that he had performed the blank test suggested by Sir Gerard Muntz by subjecting specimens to immersion in oil at temperatures up to 360° C., but found no cracking, even of highly stressed tubes.

J. L. Haughton stated that the position of the eutectic found by Miller was in accord with the observations of T. E. Rooney (221, Discussion). The very careful work of Gurevich and Hromatko, however, showed the eutectic to be at 1 per cent Cu. He believes, therefore, that more work on this problem is necessary.

139. The Attack of Molten Metal on Certain Non-Ferrous Metals and Alloys. H. J. Hartley, *J. Inst. of Metals*, 37:193-214 (1927). 17 Figures. 16 Tables.

The author feels that the same mechanism causing intercrystalline embrittlement is at work in the attack of various chemical reagents and molten metals on solid metals. The penetration was studied of tin and solder into copper and 80:20, 70:30, 64:36, and 61:39 brasses.

The magnitude of the attack seems to depend greatly on the tin content of the solder. In attack by solder, residual stresses are liable to produce rupture only when the temperature rise is sudden, since at 200° C. internal stresses are rapidly released.

Rhead [*Metal Ind. (London)*, **18**:365 (1921)] states that the attack of molten metals follows a course indicated by *gamma* solution between the crystals. It is difficult to see how this explains the attack of solder on fully annealed copper or on 80:20 brass, or the occasional penetration through a crystal.

The amorphous cement theory offers a simple explanation of inter-

crystalline penetration, since the loosely packed amorphous material
is supposed to be more soluble than the crystalline. It apparently fails
in the case of cold-worked material, for such is less rapidly attacked
by mercury than soft or medium-hard material.

Hartley agrees with Desch [*Trans. Far. Soc.*, 17:17-21 (1921)]
that the explanation is not to be found in any theory of normal con-
ditions at the grain boundaries, *i.e.*, that mercury or other reagents
cannot produce intercrystalline weakness that does not already exist.
The initial attack is probably due to local abnormal conditions or
impurities as it is apparently haphazard. Once started the only con-
dition for further attack may be high tensile stress.

If the entrance of tin into a grain boundary is accompanied by
the formation of a solution of two intermetallic compounds (which is
incapable of taking its share of the tensile stress due to its brittleness)
the ability of an attacking metal to unite in combination with a con-
stituent of the attacked alloy will, to a large extent, determine the
attacking power of the metal.

Assuming that the attacks by molten tin and by mercury at ordi-
nary temperatures are analogous, a work-hardened material free from
internal stress will resist attack far more effectively than annealed
brasses, yet considerable decrease in tensile strength may be expected
even in these.

Discussion. F. C. Thompson stated that Hartley's evidence seems
to be perfectly satisfactory in showing that an additional weakness
is present when brass is attacked by some molten metal. He feels that
the molten metal is the main cause of trouble but also feels certain
that a very small crack must exist in advance of penetration.

H. J. Hartley in reply to Prof. Thompson states that in a number
of instances of solder penetration into broken test pieces he could find
no crack formed in advance of the solder.

140. The Diffusion of Bronze into Steel at High Temperatures.
M. R. Perrin, *Rev. Mét.*, 21:531-538 (1924). 18 Figures.

With certain precautions one may coat a piece of steel with an
adherent layer of bronze by pouring the bronze on to the surface of
the steel. A study of specimens thus formed reveals a mutual penetra-
tion of the bronze and the steel, a phenomenon allied to cementation
and differing according to the kind of steel.

All oxide must be excluded, therefore the steel surface is first tinned
in order to be able to operate in the air. Perrin used quite a large

quantity of bronze, in order to hold it at a high temperature as long as possible after pouring and thus secure maximum interpenetration of the two metals. A study was made of the bronzing of steel shells and cylinders.

MECHANISM OF BRONZING:

Bronze diffuses into steel at 1000° C., a true metallic cementation resulting, the depth of penetration being greater the longer the time of contact at a high temperature. This explains why:

1. Such a bimetallic piece may be heated to 800° C. without loosening the two metals.

2. In a tensile test the break occurs in the bronze and not at the surface of contact, evidence of a continuity of mechanical properties (although rapidly varying) across the boundary surface. Impact specimens, however, fail at the boundary.

3. Penetration is small and nearly uniform for C steel, pearlitic Ni-Cr steel, but deep and anisotropic for austenitic Ni steels. With martensitic steels the results are not satisfactory, due to the formation of cracks. In the case of thin pieces avoid Ni steel.

Perrin manufactures bronze lined steel shells for bushings of electric motors.

141. **Rapid Analysis of Babbitts and Bronzes.** E. W. McMullen, *Chemist-Analyst*, 35:9-11 (1921). [From *J. Inst. Metals*, 29:694 (1923).]

The following method of analysis is quoted.

"Dissolve 0.5 gram in concentrated HNO_3, evaporate to dryness and bake several minutes. Digest 15 min. with 5-10 cc. HNO_3 and 75 cc. H_2O. Collect the insoluble Sn and Sb compounds on a pulp filter, wash, ignite, and weigh as $SnO_2 + Sb_2O_4$. (For very accurate work test residue for Fe, Pb, and Cu.) Evaporate filtrate with 7 cc. H_2SO_4 until latter fumes strongly, cool and treat with 100 cc. H_2O and 20 cc. alcohol, to ppt. the $PbSO_4$ which weigh. Boil to remove the alcohol, add 25 cc. H_2SO_3 and a little KI solution. Collect CuI on a Gooch crucible, wash and dry at 110° C. and weigh. Boil solution to expel SO_2, oxidize, and treat with NH_4OH. Ignite precipitate of Fe and Al hydroxides, weigh and determine Fe volumetrically. Zn is determined in the ammoniacal filtrate by precipitate as phosphate. A separate trial is used for the estimation of Sb, by solution in hot concentrated H_2SO_4 fol-

lowed by titration with KmnO$_4$ in the presence of HCl and tartaric acids".

142. The Analysis of Copper-Tin Alloys. W. Gemmell, *J. Soc. Chem. Ind.*, 32:581-584 (1913).

The author gives a method of analysis of tin bronzes without first separating the tin with nitric acid. The tin is kept in solution and the copper is precipitated electrolytically.

Dissolve 2 grams of the alloy in 20 cc. of a mixture of equal volumes concentrated HNO$_3$ and H$_2$SO$_4$ with 30 cc. water. Boil to expel oxides of nitrogen, cool, dilute with 50 cc. water, and deposit the Cu electrolytically preferably with rotating Pt gauze electrodes. Pb does not interfere.

If Pb is to be estimated, dissolve 5-10 grams of the alloy as before, evaporate until fumes of H$_2$SO$_4$ are given off, dilute to a strength of 25 per cent, boil and dilute until the mixture contains 7 per cent H$_2$SO$_4$ by volume. The Pb thus precipitated will be quite free from Sn.

To estimate Sn, dilute the solution remaining after electrolysis to 500 cc., boil, filter through double Swedish filter paper, and wash with 1 per cent H$_2$SO$_4$ or HNO$_3$.

Directions are given for estimating Fe and Ni.

Zinc is estimated in the final filtrate by evaporating this with H$_2$SO$_4$, adding an excess of NaOH, acidifying with acetic acid and electrolyzing.

143. The Electrolytic Analysis of Copper Alloys. J. G. Fairchild, *Met. & Chem. Eng.*, 11:380-382 (1913).

The author uses stationary electrodes, the cathode a dish, and the anode a spiral. He gives comprehensive directions for the determination of Cu, Sn, P, Zn, Fe, Mn, Ni, and Al in copper alloys, also precautions to be observed. G. W. Thompson's procedure for the analysis of white metals is given. The original paper should be consulted.

144. On a Rapid Method of Estimating Phosphorus in Bronzes. T. E. Rooney, *J. Inst. Metals*, 20:103-104 (1918).

Dissolve 0.5-2 grams drillings in 20 cc. strong HNO$_3$ and 10 cc. strong HCl (or 60 cc. 1.135 HNO$_3$ and 10 cc. HCl). Digest without boiling until the red fumes are gone. Dilute to 70 cc., cool, add 40 cc. 0.96 NH$_4$OH followed slowly with shaking by 35 cc. nitromolybdate solution. Let stand 1-2 hr., filter off ppt. (preferably on pulp) and

wash with H_2O until acid-free. Transfer filter and ppt. back to flask and run in an excess of $N/20$ Na_2CO_3 from a burette, titrate with $N/20$ H_2SO_4 using phenolphthalein (1 cc. $N/20$ Na_2CO_3 = 0.00337 per cent P on 2 grams).

The analysis is best carried out in an Erlenmeyer flask, using a rubber stopper during the final shaking.

The digestion with acid must be long enough to oxidize all the P. Boiling or heating must not be long or the Sn will precipitate.

The author compares his method with a gravimetric method in which the SnO_2 containing P is mixed with Hepar mixture and fused. Dissolve the melt in hot H_2O, add a little HCl to precipitate the Sn. Filter, boil the filtrate to remove H_2S. HNO_3 is then added and the solution boiled down, P is precipitated and estimated as Mg pyrophosphate.

A table is given comparing the results of the analysis in both ways. The maximum difference is 0.03 per cent of the whole alloy.

145. The Determination of Sulfur in Brass and Bronze. G. Thurnauer, *J. Ind. & Eng. Chem.*, 2:293 (1910).

The author has adapted to the analysis of copper alloys, a method used for the determination of sulfur in organic compounds.

One gram of filings which will pass through a 100-mesh sieve are mixed with 6 grams of a mixture of two parts potassium chlorate to one of sodium carbonate.

A small quantity of sodium carbonate is placed on the bottom of a wrought iron crucible, next the above mixture and then a little of the mixture without the filings. The crucible is covered and heated over a Bunsen burner, at first slowly, and then to a high temperature.

The melt is digested with hot water and filtered. The filtrate is acidulated with hydrochloric acid and boiled to remove all carbonic acid. The solution is neutralized with ammonia, acidified with HCl, and the sulfur precipitated with barium chloride.

146. Analysis of Babbitt Metal; Alloys of Tin, Antimony, Lead and Copper. E. W. Hagmaier, *Met. & Chem. Eng.*, 16:84-85 (1917).

Before analysis, the sawings or filings should be gone over with a magnet.

Sb: Dissolve 1 gram in 10 cc. H_2O and 25 cc. H_2SO_4 on a hot plate, cool, add 100 cc. H_2O, 10 cc. HCl, boil 10 min. to expel sulfuric fumes. Cool, add 100 cc. H_2O and titrate with $KMnO_4$.

Sn: Dissolve 0.5 gram in 30 cc. HCl, heat gently, if impossible to obtain complete solution add a little $KClO_3$. Add 150 cc. H_2O and 80 cc. HCl. Put a strip of ingot iron in the flask, cover and boil until all the Sn is reduced. Cool quickly, remove Fe and titrate with 0.1 N iodine solution.

Pb: See Abstract No. 157.

Cu: The treatment is the same as for Sn to the point where the $PbSO_4$ is filtered off. When the precipitate is washed so that no Cu remains discard precipitate, add 2-3 cc. HCl to filtrate and some pieces of Cu-free Al, place on the back of hot plate and the Cu will be thrown out.

Dissolve 0.5 gram Cu foil in 5 cc. HNO_3. Neutralize with Na_2CO_3, acidify with (1:3) acetic acid and cool. Add 3 grams KI and stir until it is dissolved. The solution will be brown with a white precipitate. Titrate at once with 0.1 N thiosulphate solution. When pale add 10 cc. of starch solution and titrate until the blue color is entirely gone. Keep concentrated, have slight excess of acetic acid. Have completely cold before adding KI, add sufficient KI and stir continually during titration.

147. Analysis of White Metal Alloys, Determination of Lead, Copper and Antimony. R. Howden, *Chem. News,* 116:235 (1917).

Pb: Dissolve 1 gram in nitro HCl, add 5 cc. concentrated H_2SO_4 and about 1 gram tartaric acid. Evaporate until the red fumes are gone, remove from hot plate and dilute. Filter off $PbSO_4$ wash, burn and weigh.

Cu. Pass SO_2 into filtrate, precipitate Cu as CuI or $Cu(CNS)_2$. Collect precipitate on a pulp filter, dissolve in dilute HNO_3, estimate Cu by the iodide or thiosulphate method.

Sb: Dissolve 1 gram in HCl with the addition of $KClO_3$, add drop by drop $SnCl_2$ solution until yellow color is bleached. Dilute to convenient bulk and blow air through for about 20 min. to reoxidize the Cu. Estimate Sb by the bromate method:

Reoxidize Sb by a standard solution of $KBrO_3$. Titrate using methyl orange. Run in bromate solution until 1 drop suddenly destroys the color. The temperature should be 60° F.

148. Analysis of Babbitt Metal. H. C. Boehmer, J. R. Gordon, and
C. W. Simmons, *Can. Chem. J.*, 4:171-173 (1920); Chem. Abstracts, 13:3106 (1920).

Dissolve 0.5 gram of alloy in 20 grams concentrated H_2SO_4 (or
1 gram in 35 cc.), cool, add 150 cc. H_2O and 5 cc. concentrated HCl.
Let stand one hour and filter $PbSO_4$ in a Gooch crucible. In the filtrate
(about 200 cc.) titrate the Sb with 0.1 N $KBrO_3$ solution and methyl
orange. Add to the solution 10 cc. concentrated HCl and 0.5 gram
powdered Sb, boil 20 min., cool in a current of CO_2 and titrate the Sn
with 0.1 N $KBrO_3$, using KI and starch as indicator.

149. Analyses of Babbitt Metal. I. B. Mintz, B. O. Lyubin, and
Ya. I. Zilberman, *Nauchnuie Zapiski*, 4:196-198 (1927). Abstract in *J. Inst. Metals*, 38:499 (1927).

"Cover 1 gram of filings in a deep porcelain dish with 5 cc. of
water and 10 cc. of concentrated HNO_3. Evaporate to dryness and
treat the residue with 7.5 N-HNO_3 to dissolve Cu and Pb salts. Filter
and wash with water containing some NH_4NO_3, add 10 cc. of concentrated HNO_3 to the filtrate, bringing the total volume to about
120 cc. Electrolyze the solution for Cu and Pb. Determine Sb and Sn
by the Tereshchenko method: dissolve 0.5-1 gram of the material in
10 cc. of concentrated H_2SO_4, boil for 5-7 minutes, cool, add 50 cc.
of water and 20 cc. of concentrated HCl, boil for 2 minutes, cool
quickly, add 100 cc. of water and titrate the Sb with 0.1 N-$KMnO_4$.
Pour the solution into 110 cc. of 6 N-HCl, add 15 grams of pure iron
wire, heat slowly and introduce CO_2 to expel air. When all the Fe
has dissolved, cool, add 5 cc. of starch solution, and titrate the Sn
with 0.1 N-KI_3 solution".

150. Electrolytic Analysis of White Metals with Tin Base.
I. Compagno, *Atti accad. Lincei*, 22(II):221 (1913).

The author gives a rapid and accurate method for the analysis
of white metals, as follows. Cover 1 gram of the alloy with 20 cc. of
1.4 HNO_3, let stand several hours and then heat on a water bath.
The tin and antimony oxides obtained contain only a little copper.
Copper and a small quantity of lead are estimated electrolytically in
the filtrate. Dissolve the precipitate in NaOH and Na_2S and electrolyze. The copper deposited with the antimony is precipitated as
CuO and estimated.

The liquid from the antimony electrolysis is heated and treated

with 120 cc. HCl. Boil until the tin sulfide redissolves. After concentrating add a little H_2O_2, then 20 grams of oxalic acid. The tin is deposited from the warm solution on a rotating cathode.

151. A Rapid and Accurate Method for the Determination of Antimony in White Metals. Anonymous, *Brass World*, 10:182 (1914).

Put 0.5 gram of sawed sample in a 12 gram flask, add 20 cc. conc. H_2SO_4, dissolve over a Bunsen burner, cool, add 15 cc. conc. HCl, then add water to about 400 cc. and titrate with a standard solution of $KMnO_4$. (Use about 1 cc. to 0.006 gram Sb.) Standardize the solution under the same conditions as the sample being run.

152. The Rapid Estimation of Antimony in Lead-Antimony Alloys. L. Bertiaux, *Chim. ind.*, 4:467-472 (1920).

Sb can be quickly determined in alloys with Pb (Sn, Cu, and Bi) as follows:

Dissolve 5 grams in 40 cc. boiling H_2SO_4 with the addition of 10 grams anhydrous K_2SO_4 or Na_2SO_4, dilute with 200 cc. H_2O, add 50 cc. HCl. Titrate with $KMnO_4$ (5.7 grams per liter) after the addition of 2 drops of a 1:1000 solution of Poirrier orange (or indigo). The slightest excess of $KMnO_4$ liberates Cl which discolors the liquid.

Sb = Fe (corresponding to cc. of $KMnO_4$) $\times$ 1.0714.

Titrate slowly with continual shaking. Fe must be absent or determined colorimetrically by NH_4CNS after titration. A series of trials leading up to the method is given.

153. A Method for the Determination of Antimony in White Metals, Etc. H. R. Fitter, *J. Soc. Chem. Ind.*, 46:414T (1927).

"A method for the determination of Sb in the presence of Sn in alloys such as white metal, solders, brass, and bronze is described. Two grams of filings are dissolved in 20 cc. concentrated HNO_3, the nitrous fumes are boiled off, and the solution diluted to 200 cc. The precipitate of oxides of Sn and Sb is filtered on a glazed filter paper and washed. The precipitate is transferred to a beaker and 30 grams of oxalic acid added and the solution made up to 100 cc. It is kept hot until clear and then diluted to 200 cc. H_2S is passed through the hot solution until the whole of the Sb is precipitated. The precipitate is collected and washed with H_2S water. The paper and precipitate are transferred to a beaker, and at this stage it may contain traces

of Sn, Cu, or Pb. The precipitate is covered with a 10 per cent solution of NaOH and warmed until all but the dark colored sulfides are dissolved. The solution is diluted and filtered and the filtrate neutralized with oxalic acid and an excess of 30 grams acid added. The solution is again made up to 200 cc. and treated with H_2S, when pure Sb_2S_3 is precipitated".

154. A Simple and Rapid Method for the Determination of Tin in Bearing Metals and Similar Alloys. J. Nagel, *Chem. Ztg.*, 46:698 (1922).

Dissolve 0.5-1.0 gram filings by boiling with 100-150 cc. conc. HCl and 2-3 grams $KClO_3$ until the excess of Cl is driven off. Add 30 cc. H_2O and 5-7 grams NaCl to raise the boiling point. A nickel strip 3 mm. thick and 10 cm.^{2} in area is immersed in the solution and this boiled three-quarters to 1 hour. Plug flask with a stopper having a bent glass tube inserted and boil 10 min. to expel the air. Pass in CO_2 and let cool in an atmosphere of this. Titrate with iodine solution (100 cc. $=$ 0.5-1.0 gram Sn), using starch for an indicator. Pb and Sb have no influence on the determination.

155. The Determination of Calcium, Sodium, and Lithium in the New Lead Alloys. E. Schurmann and W. Böhm, *Chem. Ztg.*, 50:709-710 (1926). Abstract from *J. Inst. Metals*, 37:579 (1927).

"One hundred grams of alloy are dissolved in HNO_3; the bulk of the Pb is precipitated as $PbCl_2$ by addition of HCl, the filtrate evaporated to dryness and the residue extracted with water. The solution is treated with $AgNO_3$ to convert the salts back to nitrates, and PbO_2 is deposited by electrolysis of the filtrate. The solution freed from Pb is evaporated repeatedly with HCl, the heavy metals, iron, and the alkaline earths are removed by successive treatments with H_2S, NH_4OH, and $(NH_4)_2C_2O_4$, and the filtrate is evaporated to dryness. The residue is heated to expel NH_4 salts, and Na and Li are separated by the amyl alcohol method of Gooch".

156. Determination of Calcium, Strontium, and Barium. L. Szebellédy, *Z. anal. Chem.*, 70:39-55 (1927). Abstract in *J. Inst. Metals*, 37:579 (1927).

"For the gravimetric determination of Ca by precipitation with an oxalate in $CH_3.COOH$ solution the more readily soluble $K_2C_2O_4$

may replace $(NH_4)_2C_2O_4$ as the precipitant with advantage. Sr may be accurately determined by weighing $SrC_2O_4.H_2O$ obtained by precipitation in a solution containing 1 cc. of N $CH_3.COOH$ per 100 cc., using 10 per cent $K_2C_2O_4$ solution as a precipitant and subsequently drying at 100° C. Slight corrections have to be applied in the case of both metals to the weight of precipitate obtained; these are set out in tabular form in the original. For the separation of Ca and Sr the nitrate solution is evaporated to dryness and the residue heated for 30 minutes at 135° C., then for 30 minutes at 180°. After cooling over anhydrous $CaCl_2$ the dry mass is extracted twice with 2.5 cc. of absolute C_2H_5OH, then with 5 cc. of anhydrous *isobutyl* alcohol. The residue is dissolved in water and the evaporation, drying, and extraction repeated, using only 10 cc. of *isobutyl* alcohol. The final $Sr(NO_3)_2$ residue is dissolved in water, the solution evaporated, and the residue dried at 135° C. for weighing. The $Ca(NO_3)_2$ solution in the mixed alcohols is evaporated and the residue converted into $CaSO_4$ by heating with $(NH_4)_2SO_4$. Ca and Ba are separated in a similar manner. For the separation of Sr and Ba the boiling solution (100 cc.) is treated with 15 cc. of N $CH_3.COOH$, 5 grams of NH_4Cl, and 10 cc. of 10 per cent K_2CrO_4 solution is added slowly. The precipitate of $BaCrO_4$ is collected next day, washed with cold water, dried at 132° C., and weighed. Sr is recovered as $SrC_2O_4.H_2O$ from the filtrate".

157. Determination of Copper in Babbitt Metal. E. W. Hagmaier, *Met. & Chem. Eng.*, 12:753 (1914).

Place 1 gram of filings in a 250 cc. beaker, add 15 cc. hot water and sufficient tartaric acid to hold in solution all the Sn and Sb, run in 5 cc. HNO_3 and boil until the alloy is dissolved. If the solution is milky there is not enough tartaric acid and the determination must be started over again. Cool and add 5 cc. H_2SO_4 and boil to expel HNO_3 (about 5 min.). Remove from the plate or the tartaric acid will char. Cool, add 5 cc. H_2O, allow $PbSO_4$ to settle and filter, washing with 2 per cent H_2SO_4. Use the precipitate to determine Pb, by dissolving on the paper with NH_4Ac and HAc, then precipitate the Pb as chromate. The filtrate from the $PbSO_4$ is made up to 400-500 cc., 1 or 2 cc. HCl is added, a strip of Cu-free Al inserted and the beaker placed on back of the plate. The Cu will be thrown out and may be filtered off and determined electrolytically or by titration.

158. The High Lead Bearing Metal Problem. R. R. Clarke, *Foundry*, 42:219-223 (1914).

The author calls a high lead alloy (copper base) one having Pb and Sn over 24 per cent of the whole and Sn less than 30 per cent of the combined Pb and Sn. The problem of making these alloys arises from the fact that Cu will absorb naturally only 3.5-4 per cent of Pb.

It is well known that Sn aids the incorporation of Pb up to a certain percentage of Sn in Cu, and above this it hinders incorporation of Pb. The use of P has recently been sanctioned. Zn must be excluded on account of its heating tendency. If Sb is substituted for Sn the castings will be brittle and treacherous. P, used as a deoxidizer, should not be more than 1 per cent of the whole and less should be used the higher the Pb content.

Cu, 80; Sn, 10; Pb, 10 may be made without stirring, though it is not bad practice to do so. Such castings sweat Pb profusely, if uncovered much above a cherry red heat.

The author cannot answer any questions regarding the control of process by addition of other elements. The author has had experience with various types of high lead bronzes, and has found that they are all failures as far as ordinary foundry manipulation is concerned, regardless of the claims of the manufacturers.

Ni or Fe-Mn may be used as an auxiliary addition, but are both inferior to Sn. The limit is probably 1 per cent Ni or 3 per cent of 80 per cent Fe-Mn. The author mentions the alloy Cu, 76; Pb, 20; Sn, 4, with 1 per cent Cu replaced by Ni, or 2 per cent Cu replaced by Fe-Mn as limiting cases. Castings of these have the following peculiarities: (1) they resent hard tamping, (2) they have a decided tendency to shrink, (3) they should be poured hot. However, if poured too hot, they will remain liquid in the mold too long, and the Pb will sink at once to the bottom if stirring ceases. The author remarks that there must be something radically wrong with an alloy which will blow up a mold that is tamped hard, or is made of wet sand, and still shrink under 23 inches of gate pressure.

Segregation is not such a vital factor in light castings, as they solidify so rapidly the Pb does not have time to sink, nor in those whose area is large compared with the volume or those poured into iron molds, in which case, gravity may be made the medium for a mechanical trick.

The Pb probably oxidizes to some extent and leaves the dross enmeshed in the Cu when it sweats out. The sweating is the greater

evil here as it makes the casting porous. The dross, however, makes the metal almost worthless as scrap. The author has examined many recastings showing long lines of dross and porosity.

The author's experience has led him to the following casting procedure as the best if virgin metals are used: Melt the metals of high melting point together first under charcoal using a reliable flux. Do not overheat. A rather dry sand should be used, uniformly tamped and vented freely. Use strong gate or sprue pressure. In pouring use a skimmer not far from the lip of the container. Pour hard and at a warm temperature. The mold should be gated at the bottom if this is possible. Uncover castings at a cherry red heat. The metal should be stirred vigorously before pouring.

159. Casting Bearings in Sand and Metal Molds. R. R. Clarke, *J. Am. Inst. of Metals*, 11/12:167-180 (1917/1918).

This paper discusses the manufacture of leaded bronzes. Difficulties arise due to the behavior of Pb in Cu. Cu dissolves only 3.5-4 per cent Pb, and its density is only 8.9 against 11.3 for Pb, while the melting points differ by 700° C. P may be added as a deoxidizer but it tends to knock down the Pb. The Sn is advantageous in that it alloys with both Pb and Cu. The author mentions Dudley's experiments to obtain a higher Pb alloy. The distribution of Pb changes, not only in casting (segregation) but also on heating above the melting point of the Pb. Hot bearings sometimes show beads of Pb on the surface. These are swept away to be replaced by others with resulting sponginess and porosity. An ideal bearing has a duplex antifrictional surface fading away into a hard compression resisting background.

Low lead alloys (Pb not more than 10 per cent) such as Cu, 80; Sn, 10; Pb, 10 with 0.5-1.0 per cent P give little trouble with ordinary care, such as vigorous stirring on adding the Sn and Pb. The sand should be tamped hard, the mold faced with plumbago, the gate should be at or near the bottom, the alloy should be poured hard and at as low a temperature as possible. The casting must be left in the sand until below the melting point of Pb.

With medium lead alloys (Pb 10-15 per cent) the above measures are imperative also. Success with such an alloy as 78-7-15 with phosphorus depends on careful attention to manipulative details. A medium instead of a large size crucible is used and stirring should take place vigorously from the bottom up. Fifteen per cent Pb is about the limit.

In high lead alloys (15-50 per cent Pb) another element or ele-

ments may be added to control the freezing points of solutions, other than pure Pb in mass. No phosphorus can be allowed. The pouring temperatures are more critical and the castings should be shaken out at a cherry red heat.

Chill castings are not very successful below 15 per cent Pb. Above 15 per cent Pb they are not as good as sand castings, having blowholes, shrinkage, and bad appearance.

160. Plastic Alloys. E. D. Gleason (in correspondence column), *The Metal Ind. (N. Y.)*, 20:74 (1922).

If the price is no object a plastic bronze as Cu, 65; Pb, 35; Sn, 5 may be used. Melt down hot under charcoal 60 lbs. common copper, add 5 lbs. of 30 per cent Mn-Cu. Stir well and add the Pb-Sn alloy in the form of small pigs. When the pot is lifted skim off the charcoal and add a fresh layer and when about to pour skim off charcoal or use skim gates. Under these conditions one may obtain an alloy with ultimate tensile strength = 25,000 pounds per sq. in., elongation = 15 per cent, compression = 0.35 per cent for 100,000 pounds per sq. in. Mn is good to prevent lead sweat and segregation. In this alloy the Mn content is 1.5 per cent.

For a cheaper alloy use 5-10 per cent of Sn, 50; Sb, 50 plus Cu and Pb to 100 per cent. This is easy to obtain free from lead sweat and segregation.

161. An Investigation of Segregation with a View of Preventing Its Occurrence in Castings Made of a High-Lead Bronze. R. E. Lee and F. B. Trace, *Trans. Am. Foundrymen's Assoc.*, 30:511-540 (1922).

Investigations on alloys of the type Cu, 70; Pb, 25; Sn, 5 led to the following conclusions: (1) Elimination of impurities and thorough mechanical mixing is not sufficient to prevent segregation although absence of these is a cause. (2) The segregated portions always contain less tin; the tin content varies by 26 per cent that of the other metals by less than 2 per cent. (3) The loss by oxidation and volatilization is greatest for the tin, but it is seldom greater than 1 per cent. (4) If the charge is not heated to above 1800° F. (980° C.), or having been heated is cooled much below this, segregation will occur. The structure indicates that the filling in process is hindered by the greater viscosity

at lower temperatures. (5) Castings made from charges heated to 2000° or 2200° F. (1090° or 1200° C.) and cooled rapidly to 1800° F. (980° C.) before pouring exhibited structure not so coarse or loose as those poured at the higher temperature. (6) Charges entirely of virgin metals require higher temperature to be entirely free from segregation. (7) Castings containing as much as 26 per cent Pb poured at 2200° F. (1200° C.) or chilled to 1700° F. (925° C.) from this temperature will be free from segregation. (8) The modulus of rupture for castings free from segregation is 14 per cent higher than for castings which show segregation. The modulus of rupture is not decreased by heating charge to the highest temperature, *viz.*, 2200° F. (1200° C.).

On removing metal from the furnace a small amount of phosphor-copper should be added to reduce oxides, then skim and stir vigorously. The sand should be comparatively dry to prevent sand burns.

162. Antifriction Metal. G. C. Holder, *Metal Ind. (N. Y.)*, 15:153-155 (1917).

In choosing a bearing metal it is important to consider both the load and speed conditions under which it is to operate. The author mentions the case of a high speed, light load machine where both tin and lead base alloys proved unsatisfactory, but the alloy Zn, 88; Cu, 9.7; Al, 2.3 gave good service.

That correct analysis of scrap used is important is self-evident. Zinc is undesirable, causing brittleness when heated, copper forms components of great hardness, aluminum is objectionable because of its low affinity for lead. Elements of low atomic volume increase friction and *vice versa*.

The method of mixing metals of high and low melting point is important. As a method of mixing genuine babbitt the author recommends first melting Cu, adding part of Sn, then the Sb and casting in molds. Next melt the rest of the Sn and then add the Cu-Sn-Sb alloy. Iron kettles can be used for remelting unless the alloy contains Zn or P.

Avoid overheating to prevent loss of Sb or oxidation of Sn. An excellent practice, in remelting is to inject superheated steam or to insert a piece of green wood to cause the impurities to rise to the surface.

For covering the bath, charcoal is not compact enough and powdered charcoal or graphite is too easily blown away. It is a good idea to use resin or better still, tallow.

If oxides are formed because of the lack of cover, fluxes such as

ammonium chloride must be used. Another efficient flux is manganese sulfate and powdered charcoal, placed in the bottom of the melting pot before putting in the alloy. This mixture strains out the dirt and reduces all the oxides except that of tin.

In the refining of scrap metal, if it is desired to lower the Cu content, introduce S and skim off the CuS. To lower the Al content use litharge and skim off the alumina. Zn can be volatilized. Fluxes for reclaiming Sn are given.

The author gives tables of mechanical properties and melting points of some antifriction alloys, a table of friction tests on two Pb base alloys, and a table of properties of Pb base alloy both at room temperature and at 200° F. (93° C.) after successive remeltings.

163. The Manufacture of White Metal for Friction Bearings.
Anonymous (Foreign Exchange), *Metal Ind. (N. Y.)*, 17:74 (1919).

An invention relates to the manufacture of lead base white metals containing small amounts of Sb, Cu, and Sn together with a certain amount of Si, which may to a certain extent serve as a substitute for Sn and Sb. The limits of Brinell hardness number are 24-35.

It is already known that Cu overcomes the tendency to segregation although rendering alloys somewhat brittle. The addition of Si obviates this defect even if the Cu is in excess of the usual proportions. Also the solidification temperature is lowered, the Cu is longer in contact with the molten mass, allowing the Sb to absorb more of it. The eutectic, consequently, is much denser and the tenacity is increased.

By adding 4-6 parts by weight of a 30 per cent Si-Cu to an auxiliary alloy "H" containing 56-62 parts Sb and 40-32 parts Cu, the melting point of the alloy "H" may be reduced.

The white metal itself is produced by fusing 76 parts Pb and 24 parts of alloy "V" which is made by fusing 15-35 per cent "H" together with equal parts Sn and Sb to make 100 per cent. The Pb content may be varied to vary the hardness. The practical limits are 15-35 per cent of "V". The purpose of "H" is to raise the temperature of solidification of "V".

From the final alloy the Sn-Sb cubes crystallize out at 320° C. against 350°-380° for alloys containing no Si. The alloy is also more dense and uniform than those without Si.

164. Selection and Use of Babbitt Metal. L. D. Allen, *Machinery,*
29:211-213 (1922).

There is more to making a good bearing metal than simply mixing
certain percentages of constituents. Some alloys are perfect at high
temperatures but segregate at low temperatures. Fluxes are often used
which are not apparent on analysis, hence certain "secret" methods.
The author's long experience leads him to recommend virgin metals in
manufacture. A babbitt should not be selected by analysis and cost
alone. He gives practical advice on melting and pouring for liners,
emphasizing the importance of pouring at low temperatures. The
lower the temperature the denser the structure. For high pressure bear-
ings Allen advises slow immersion in water immediately after solidi-
fication.

If a high grade tin base genuine babbitt is poured too hot or against
an overheated mandrel or shell, minute cracks will form in the liner
which will gradually become larger under shaft vibration—allowing
the lubricant to work between the liner and the backing.

Due to the low thermal conductivity of oil the film thus formed
prevents conduction of the heat from the liner, which may be heated
to the point of fusion.

If a moderate priced lead base alloy is cast when overheated, it
will be coarse and brittle.

The difference in expansibility between iron or steel and babbitt
causes a condition of stress in the solidifying metal, sometimes great
enough to cause loose liners. Use as low a pouring temperature as
possible.

165. Melting White Bearing Alloys. "Celsian", *Foundry Trade J.,*
31:165 (1925).

White metals are prepared most economically by metal refiners
from different varieties of scrap. Fluxes are seldom added to virgin
metals but they are protected from oxidation by a layer of grease or
cheap oil. Zinc chloride is sometimes used to clean off oxide but its
use is not recommended as some Zn may combine with the alloy.
Metallic sodium is also used but it impairs the toughness and hardness
of the alloy.

In making an alloy from new metals, Pb is melted first, then the
Sb or Pb-Sb alloy, then part of the Sn, and finally the remainder to-
gether with Cu or a Cu-Sn-(Sb) alloy. Sn-Pb-Sb alloys should be

poured at as low a temperature as possible, but not too low when Cu is present or some of it will be removed when skimming.

When melting white metals from skimmings, borings, etc., use a flux of 30 parts potassium ferrocyanide, 20 parts soda ash, 10 parts borax added a little at a time to the waste.

Nickel is usually introduced as nickel-tin when the alloy has reached a fairly high temperature.

Alloys for ship propeller bearings sometimes contain several per cent mercury, with the view of resisting corrosion, but the cost is high.

166. Electric Furnace Refractories. A. F. Greaves-Walker, *Chem. & Met. Eng.*, 23:933-936 (1920).

Magnesite linings as low as possible in silica are recommended for electric furnaces used for melting bearing metals (Cu, Sn, Pb, Sb), especially those having a high lead content.

For bronzes, a silica lining is preferable but magnesite can be used if not too much zinc is present in the alloy.

167. Bearing Metals and Alloys Made by Compressing the Constituents. W. Guertler, *Metallurgie*, 7:264-268 (1910).

The author refers to the work of Friedrich, who added foreign constituents to alloys when they were in a pasty condition. Guertler has produced bearing metals directly from a mixture of the powdered constituents. His plan is to use lead with perhaps a small amount of hardening constituent as the matrix of the bearing metal, and a cheap hard metal as iron, steel or cast iron for the hard, load carrying particles. These constituents cannot be alloyed by melting together, as a system of two liquid phases results. Segregation cannot be prevented even by the most violent stirring.

Guertler produced a mixed powder of iron and lead either by precipitating lead out of dilute solution onto iron filings, or by mixing iron filings with fine lead-tree crystals. The powder was heated to over 250°-300° C. and pressed into molds. Complicated shapes could be produced in this way.

168. On the Electrolytic Production of Calcium Alloys and Calcium. W. Moldenhauer and J. Anderson, *Z. Elektrochem.*, 19:444-447 (1913).

The authors prepared Ca, and Ca-K, Ca-Zn, and Ca-Pb alloys by electrolysis of fused salts.

For an equilibrium diagram of the system Pb-Ca they refer to the work of Donski, who, however, could not obtain alloys containing over 12 per cent Ca by melting the constituents together. The maximum melting point obtained was 650° C.[247]

A CaCl₂, 85 per cent; KCl, 15 per cent mixture was electrolyzed and alloys free from K were obtained, containing 5.8 per cent and 10.2 per cent Ca, with current efficiencies of 39 per cent and 33 per cent respectively, which was worse than for electrolysis yielding Ca-Zn.

With a CaCl₂, 40 per cent; KCl, 60 per cent mixture at 740° C. the same trouble was experienced as with Ca-Zn, *i.e.*, small drops of Ca rose to the surface and burned up. Finally a system consisting of two liquid phases was obtained with 3.4 per cent Ca in one phase and 81.8 per cent Ca in the other, the current efficiency being 22 per cent on the average. Neither layer was free from K, the lead rich one containing about 0.95 per cent.

168a. The Co-Deposition of Copper and Graphite. C. G. Fink and J. D. Prince, *Trans. Am. Electrochem. Soc.*, 54:315-321 (1928). (Part of thesis submitted by J. D. Prince toward a degree in chemical engineering at Columbia University.)

This paper gives the results of attempts to make a self-lubricating bearing metal by the codeposition of graphite and copper, it being thought that a more homogeneous product might be obtained this way than by the usual method of compression at a high temperature. Also the material might be plated directly on to the journal.

Graphite was used in the form of Aquadag, which consists of a suspension of finely divided graphite in an ammoniacal solution, which is stabilized with tannin. If Aquadag is electrolyzed the graphite particles migrate to the anode, but if sulfuric acid is added they migrate to the cathode. Codeposition of graphite and copper was secured by adding Aquadag to a copper sulfate solution, which was acidified with sulfuric acid. The introduction of additional stabilizer in the form of gelatin was found to be necessary, as the amount of tannin in the Aquadag was insufficient to protect the colloidal particles of graphite under these conditions. About one gram of gelatin per liter was necessary.

The adherence of the deposit was unaffected by the concentration of graphite, but was affected by the acid concentration, the best acid concentration being between 100 and 200 grams per liter. Increasing the graphite concentration above 13.1 grams per liter apparently did

not increase the amount deposited. All deposits were brittle as laid down but the brittleness could be removed by annealing at red heat for several hours.

Some trials were made at 55° C., and at this temperature the gelatin appeared to be detrimental to the deposit.

The method is entirely feasible and as much as 16 per cent graphite (42 per cent by volume) may be deposited in this way. No bearing tests were made.

169. **The Uselessness of Phosphorus in Lead-Base Alloys.** Anonymous, *Brass World*, 7:159 (1911).

The fact that P has been used to good advantage in bronze and in liquefying thick tin alloys has led manufacturers to try it on Pb base white metals. It causes no apparent beneficial change, however. Arsenic, chemically similar to it, is frequently used as a deoxidizer. The separate addition of As is rarely necessary because it occurs in most antimonial leads.

170. **Research on Occluded Gases Contained in Alloys of Copper.** G. Guillemin and B. Delachanal, *Rev. Mét.*, 8:1-6 (1911).

The authors applied the technique they had developed for the determinations of gases in brass, to such determinations in other samples of brasses, bronzes and tin. In regard to the bronzes they conclude:

Phosphor bronze contains little occluded gas, that present being carbon dioxide or hydrogen. Phosphorus thus appears to diminish the solubility of hydrogen in the metal, as has been found in the case of cast iron and steel.

The tin of commerce appears to contain a small amount of gas consisting of hydrogen and the monoxide and dioxide of carbon.

The metals studied, when free from blow-holes and dross, did not "spit" like solidifying silver, cast iron or steel.

Gas can be extracted only by heating the metals up to their melting point in vacuo, or at least in a rarefied atmosphere.

171. **Gas Absorption and Oxidation of Non-Ferrous Metals.** B. Woyski and J. W. Bocek, *Trans. Am. Inst. Mining Met. Eng.*, 68:861-872 (1923).

Oxidation may be overcome by the use of deoxidizers or avoided by protecting the molten metal with a flux. The absorption of gases is more difficult to overcome.

Gassing may be due to superheating. If for any reason the metal has to be kept in the furnace after it is ready for pouring, the operator may try to avoid overheating by keeping a mild fire, but this is unfortunately a reducing one which results in gassing the metal. A dirty, slaggy furnace may result in gassing, due to the long time of heating necessary in the uncertain atmosphere. Sulfur in the metal may produce gas holes as a result of its action with the occluded oxides. Newly-lined or damp ladles may cause gassing. The most important source of gassing, however, is the furnace atmosphere. The burners should allow complete mixing of air and fuel before they reach the furnace. Oxidation and gassing may be remedied by proper furnace practice. Gassed metal may be restored in a relatively hot and oxidizing furnace.

Bronzes are liable to be gassed in a reducing atmosphere. Tin sweat is due to the liberation of the gas absorbed and occurs most frequently in the riser.

In the case of aluminum bronzes, alumina forms while pouring if there is any agitation. A negligible amount of alumina is formed on melting, but it rises to the surface. The use of deoxidizers is common, but probably because they act as degasifiers. Al bronze is less subject to gassing than pure copper. Al does remove the gases absorbed by the Cu. The gases are probably hydrocarbons or carbon monoxide. The atmosphere should be oxidizing.

Two small pots of the alloy Cu, 90; Pb, 10 were melted side by side and the metal badly oxidized, the oxide was mixed in by stirring. One pot was then fluxed and both let cool slowly in the furnace. The fluxed metal did not show a trace of oxide, but the other produced a red powder, consisting of CuO, 66; PbO, 33; SiO_2, 1.7. This was not very evident from the microscopical examination as the red powder occurred in pellets covered by a gray skin, which at first were taken for particles of lead. The oxide was evident, however, on machining.

In bronzes the tin oxide floats to the surface in the form of crystals. Theoretically this oxide cannot exist in the presence of zinc, but in practice it sometimes does occur with zinc.

Discussion. R. J. Anderson stated that a reducing atmosphere is the orthodox practice for non-ferrous alloys. Proof should be given that badly oxidized or gassed metal can be restored as the authors say. He pointed out that atmospheres are called oxidizing or reducing, though no actual analyses are given.

B. Woyski replied that the character of the atmosphere was judged solely by the color of the flame as the analyses varied widely in the different parts of the furnace.

H. M. St. John and V. Skillman took exception to melting alloys of copper in an oxidizing atmosphere.

B. Woyski replied that a neutral atmosphere was most desirable but difficult to maintain. Their atmospheres were only slightly oxidizing. The metal was always covered with flux. He said that most foundries used the oxidizing flame because it caused faster melting.

172. Production of Large Bushings. Ch. Vickers, *Foundry*, 51:363-366 (1923). 2 Figures.

Two types of porosity exist: visible, caused by gases existing in the solidifying metal or having their source in the mold; and the invisible, intercrystalline kind. Some explain the latter kind by an expansion of the individual crystals followed by contraction. This explanation does not seem adequate as this type of porosity is profoundly changed by the method of gating, some methods producing good, others worthless, castings for holding liquid or gas pressure. The author explains this porosity as due to the eutectic draining to the lower part of the casting after the rest of the metal has solidified. Accordingly this could be prevented by gating so that there is always a head of liquid metal in a position to fill any cavities arising in this manner. This has been done by Parry. It also explains why risers function to build sound castings and why chills are valuable.

A top pouring of bushings in the horizontal position would require a large reservoir of liquid metal on top. If the mold were inclined this reservoir would not need to be so large, but the metal would still be liable to spatter against the core and include air. The author advocates gating at the lower end of the inclined mold. An adequate riser must be provided, and the head of metal must be sufficient to force the gases out of the mold. The core must be well vented. The metal must be poured hot. Details of molding are given.

173. White Brass Bearing Metals as a Substitute for High Grade Babbitt Metal. L. D. Staplin, *Am. Machinist*, 49:479 (1918).

The author advocates the substitution of high tin babbitts by white brass containing not over 70 per cent Sn in order to conserve tin. It is an excellent bearing metal when properly cast and costs considerably less than the best babbitt.

Use a clean ladle or crucible, heat slowly and sprinkle with sal-ammoniac before the metal is completely melted. (The right amount is judged by the appearance of a black spot about 1 in. diam. in the center of the ladle.) Do not let the metal become red-hot. It melts at 750° F. (400° C.). It is necessary to preheat both mandrel and box. Important work should be peened.

Lubrication of white brass liners should be liberal and the bearing well aligned. If the bearing heats at first do not use water but keep well lubricated, even adding graphite to the oil. It will eventually seat itself and cool down.

174. Technology of Bearing Metals. H. Müller, *Verkehrstechn.,* 1927, p. 858. (Abstract by Przygode.)

Former rule of thumb methods in casting and lining bearings have given place to scientifically controlled operations in which pouring temperatures and temperatures of bearings, backs and molds are measured and brought to desired values before casting. To reduce to a minimum any difference in shrinkage of back and lining, the former should be heated to a high temperature, but its design should be such that it cools as nearly as possible at the same rate as the lining. Quite different pouring and mold temperatures are needed for the different Reichsbahn standard bearing metals.

175. The Applications of Die Castings in Aircraft. C. Pack, *Aviation,* 4:298-299 (1918).

The author describes the processes of die casting. The minimum quantity which can be made economically depends on the amount of machining saved. The author's experience is that die casting is not practical in less than 1000 lots. He gives the compositions of the bronzes and the bearing linings used in this process:

Bronze backs: Cu 85, Zn 5, Sn 5, Pb 5;   Cu 84, Pb 9, Sn 5, Zn 2; Cu 89, Sn 10, P 1;   Cu 80, Sn 10, Pb 10;   Cu 82, Pb 15, Sn 3.

Linings: Sn 90, Sb 5.5, Cu 4.5;   Sn 89, Sb 7.5, Cu 3.5;   Sn 89, Sb 7, Cu 3; Sn 84, Sb 9, Sn 7;   Sn 90, Cu 10.

The method of joining the lining to the back is criticized. It has long been recognized by engineers that anchoring with undercuts is not dependable. In the author's opinion the use of both undercuts and soldering on the same job is poor practice and a waste of time. Any mechanical anchoring is useless if the solder melts. The lining should

hold all over, up to the melting point of the solder. Mechanical anchoring has proved a failure in auto and aero work.

The author criticizes "ringing" tests in that they detect, only some of the poorly bonded linings. The only test he knows of is to break the bearing to pieces and try to separate the lining from back. A thin lining of comparatively soft babbitt makes the best bearing. Hard linings have caused serious trouble.

176. Babbitting Large Bearings by Centrifugal Machine. F. C. Hudson, *Am. Machinist*, 59:150 (1923).

To secure dense babbitt linings the General Electric Company has built a centrifugal babbitt casting machine for bearings 12 in. diameter. The bearing shell is first heated to near the melting point of the babbitt, while this is heated slightly higher than is the usual practice. The machine is run at a peripheral speed of 1200 ft. per min. It takes about 3 hours to complete the babbitting of a 12 in. bearing. The actual running time of the machine is only 5-7 min. Babbitt linings thus cast have uniform density and do not require peening.

177. Casting Bushings. J. L. Jones, *Metal Ind. (N. Y.)*, 15:82 (1917).

In answer to a query regarding the best way to cast bushings for auto and high speed work, Jones replies that sand castings are liable to be porous and dirty with sand, also cool too slowly, giving too coarse a grain. The best way is to use so-called "stock sticks", *i.e.*, chill cast rods 2-3 ft. long of the proper diameter. These rods when drilled out make excellent close-grained bearings. The large amount of turnings produced can be used over again.

178. Making Thin Linings. J. L. Jones, *Metal Ind. (N. Y.)*, 17:232 (1919).

In answer to a query regarding the manufacture of thin linings for which Lumen bronze was unsatisfactory, being too brittle, Jones replies that Sampson metal (Zn, 88; Cu, 4; Al, 8) is somewhat softer and tougher than Lumen metal (Zn, 100; Cu, 5-20; Al, 2-10), though he doubts very much if Zn base alloys are tough enough to suit the requirements.

It is customary for manufacturers requiring thin linings of genuine babbitt to roll the same into thin sheets, press into tinned bronze backs and heat to solder in place.

He suggests that heavy, rolled sheet zinc might be suitable. Shells might be pressed from this and given a thin lining of babbitt.

179. **Babbitting without Tinning.** W. J. Reardon, *Metal Ind. (N. Y.),* 18:283 (1920).

In answer to query regarding the babbitting of die-cast connecting rod bearings without tinning, Reardon replies that the following is the practice with some manufacturers. The shell should be hot and clean, but no acid should be used. Some do not even machine the shell but babbitt after dipping successively in aqua fortis, sulfuric acid, cold water, and hot water. This is a good job if properly done and the babbitt is not overheated. However, tinning cannot be beaten for a sure job.

180. **Separation of White Metal and Gun Metal Borings.** R. H. Walton and G. T. Bailey, *J. Soc. Chem. Ind.,* 34:943-945 (1915)

This paper deals with the problem of separating white metal and gun metal borings arising in the locomotive shops in New South Wales. Liquation on an iron plate or in a furnace is possible only in the case of coarse borings. The borings cannot be smelted straight and used for castings on account of the high Sb content (0.6 per cent).

The procedure is as follows: The borings are shaken on a quarter inch sieve and the coarser part is separated by liquation. The fines are taken to a magnetic separator and from there to classifiers where they are separated into three grades. The two coarser classes are taken to furnaces consisting of two concentric iron pipes. The inner pipe rotates and is heated externally by a gas burner. The metal passes onto a revolving screen in the inner tube, which has a mesh smaller than that of the last classifier. The liquid white metal passes through the screen into the inner iron pipe, collects at the bottom thereof and is run off into molds. The borings pass on to the foundry. The finest class is small, probably will have to be smelted, and the bulk of the Sb removed by oxidation.

181. **Method of Separating Bronze and White Metal Borings and Turnings.** G. Frederick, *Metal Ind. (London),* 9:71 (1916).

Separation of bronze and white metal may proceed by two different methods: (1) by difference in specific gravity and (2) by difference in melting point. The difference in gravity is generally small so the

second method is usually followed. The author criticizes the use of classifying screens as these would be continually getting blocked by such shaped particles as turnings.

He suggests a system whereby turnings and borings are spread on the surface of a corrugated iron plate which forms the top of a furnace, and slopes downward in the direction of the corrugations. The slope is not steep enough for the particles to roll down. The white metal melts and runs down the channels. The disadvantage is that the gun metal oxidizes somewhat.

Another process for small shops is to hand-pick out the larger pieces, place in a crucible, heat not much over the melting point of the white metal, skim off the bronze with a perforated ladle. Such bronze can be used in the preparation of any Cu-Sn alloy and the white metal for bearings of lesser importance, because it is poor in Sn and Sb.

182. The Recovery of White Metals from Drosses. A. Bregman, *Metal Ind. (N. Y.)*, 14:103-106 (1916).

The different types of drosses, *viz.*, solder, tin, lead, hard (Pb-Sn-Sb) and babbitt drosses may usually be distinguished by an experienced person. Operations of dross recovery in a reverberatory furnace are:

Smelting: (1) Blowing in: Fire up to as high a temperature as possible, shovel in the charge, let it smelt an hour or two, stir with a hoe after it has melted and close the charge door. Fluxes may be used, such as sodium bisulfate, scrap iron, and coal dust, the latter rather sparingly. (2) Tapping: Drive out the tapping bar and keep the metal flowing through the hole with red to white hot running bars and rake out the material left in the furnace. The metal is cast for further refining and the matte and slag treated in the blast smelter to recover Cu and Pb together or they may be recovered separately.

Sweating: (3) Pigs are charged into the furnace just hot enough to melt the Pb, leaving the tap hole open. The metal trickles out into the kettle, the slag is raked out and remelted with the other dross.

The author gives a discussion of the mechanical and metallurgical difficulties. Too thick a slag can be remedied by the use of a sodium bisulfate or scrap iron flux. Too much oxide left in furnace can be remedied by the use of fine coal. A list of the necessary equipment is given.

183. The Treatment of Metal Residues and Scrap. 1. Treating White Metal Residues in the Melting Pot. A.—The Design, Building, Care and Firing of Melting Pots. E. T. Richarz (E. R. Thews), *Metal Ind. (London)*, 27:161-164 (1925). 6 Figures.

Melting pot furnaces are easily and quickly built. Compared with reverberatory furnaces they are extremely cheap, occupy little space and do not require trained and skilled operators. Their heating and working efficiencies compare well with those of reverberatory furnaces and the loss of metal by fuming is insignificant.

Material Used for Melting Pots. The material of melting pots must withstand heavy stresses and strong chemical action. The commonly used material is gray cast iron. The best gray iron for this purpose is perhaps Fe; total C, 3 per cent; combined C, 0.3-0.7 per cent; Mn, 2 per cent; Si, 2 per cent; S and P, as small as possible. Gray iron pots are suitable for small quantities of metal, but for large lots steel should be used. Under similar conditions, steel will last three times as long as gray iron even with two-thirds the wall thickness. The difference in cost is slight. With gray iron pots 45 to 60 charges of lead can be melted, with steel pots at least 100 to 125 charges with reasonable treatment before showing signs of weakening. Best results are obtained with steel containing 2 per cent manganese or chromium.

Shapes of Melting Pots. The hemispherical type of melting pot is commonly used. Most melting pots are too flat, causing too great a surface of metal to be exposed to the air, with consequent oxidation and lowered efficiency. The depth of a melting pot should be 6 to 10 inches greater than the radius. The thickness should gradually become greater toward the bottom. Good dimensions for a 3.5 ton lead pot are: diameter = 40 inches, depth = 26 inches, thickness = 1 inch at rim and 1.5 inch at center of bottom, rim width = 4 inches.

It is uneconomical to refine lead in lots of less than 7 or 8 tons. Pots to contain this much lead should have a supporting ring half way up.

Lead may be refined by gravity liquation from a pot with an outlet in the bottom, but this is not usual on account of the high temperature required. Zinc may be refined by liquation in a deep pot, which allows the under layer to lie undisturbed while the upper is being treated. This type of pot should have a depth 15 inches greater than the radius.

A liquation pan for refining white metals, particularly those rich in tin, also scrap, dross, rich ashes, etc., consists of two strong gray iron plates inclining into an iron trough. The material to be liquated is placed on the plates, which are heated from below and the molten metal runs down into the trough and out of this into a small iron or fireclay ladle.

Melting Pot Hood. The hood should be large enough to take up a certain amount of fumes before charging them into the flue. The flue should be wide enough to take care of all the fumes and steam generated. The inside diameter of the hood should conform to that of the pot. The flue should be telescopic to permit raising and lowering and is usually made of one-tenth inch sheet iron.

Building-in the Melting Pot. For efficiency, the products of combustion must be led once or twice around the pot. The channels must be large enough for the free passage of the gases. To prevent burning the bottom, this should be at least 12 inches above the grate. If gas fuel is used the tip of the flame should not reach the melting pot. No forced draught or secondary air should be used. The rim of the pot should be about 25 inches above the floor.

Treatment and Care of Melting Pots. The life of melting pots depends primarily on the care used in melting operations. (1) The empty pots should never be exposed to high temperatures. The fire should be small to start with and gradually built up as the pot is filled with metal. (2) Large amounts of metal should never be allowed to freeze in the pot. When the eutectic freezes it fills up all spaces between the metal and walls of the pot, making an absolutely tight fit of the hard block of metal in the pot. On reheating, the lower portion of the metal will melt, expand and thus give rise to dangerous stresses. (3) Highly heated metal streams should never bear down on the unprotected bottom of the pot. If there is not enough metal in the pot, a large piece of sheet iron should be placed in the pot to take the first blow of the stream. (4) Heavy slabs or bars should never be thrown in the pot from full height, they should be let slide down the sides. (5) The pot should be cleaned as often as possible with a strong steel brush, and then washed with a thick emulsion of lime to protect against corrosive action. (6) The most exposed parts of a melting pot are: (a) the point where the draught directs the flames against the front section of the bottom or where the gas flame tip touches it; and (b) the place where the fire gases enter the connecting flue leading to the flue channel encircling the pot. To prevent burning through at

these places, the pot should be turned part way around at least once a week.

Fuel. The most harmless fuel is lignite, but it has the disadvantage of low calorific value and burns down too quickly due to its structure. Unless strong and hard it should be briquetted to avoid loss by dusting and by falling through the gate. Long flame channel coal is undoubtedly the best for heating melting pots. It gives a soft and even flame and is free from the disadvantages peculiar to lignite. Short flame furnace coal may also be used, but its flame is slightly cutting, though it will not harm a good melting pot. Coke is not conducive to long life of pots but is much used on account of its long combustion period. Oil should never be burned under iron melting pots because of the impossibility of regulating to produce a soft flame without killing it or wasting fuel. Coal gas is unobjectionable if the flame does not touch the pot. To soften the flame, less primary air than necessary to burn all the gas should be used, air entering through the furnace door completing the combustion.

184. The Treatment of Metal Residues and Scrap. 1. Treating White Metal Residues in the Melting Pot. B.—The Production of White Metal Alloys, Zinc and Lead. E. R. Thews, *Metal Ind. (London),* 27:307-310 (1925).

The recovery of metals from residues, scrap, etc., may be divided into two main branches: (1) Smelting of ashes, dross, etc., which necessitates the use of a reverberatory or blast furnace. (2) Remelting purification of alloys and residual metals, cuttings, scrap, etc., which can usually be done in steel melting pots.

Smelting of lead ashes has been dealt with in another paper. The present paper is concerned with the treatment of metallic scrap and the products of the smelting treatment.

Pure virgin metals are rarely used for alloying white metals. The alloy scrap used in their manufacture is rarely pure enough to be used directly. The price of scrap varies with the content of impurities, so that within certain limits, the most impure scrap may be the most economical to use. In most cases the impurities can be worked into some paying alloy.

Preliminary Reverberatory Furnace Treatment. The impurities in white metal scrap having the major constituents lead, tin, and antimony are copper, zinc, iron, arsenic, and sulfur. Small amounts of these elements may be removed in the melting pot, but larger

amounts require the reverberatory furnace. Copper cannot be removed in the melting pot, sulfur very poorly, removal of zinc is theoretically possible but is economical only if less than 0.1-0.2 per cent is present, the elimination of iron in the melting pot is always possible.

The ideal furnace for eliminating copper has a comparatively deep hearth, that for zinc, a wide and shallow one, but as these impurities usually occur together, a compromise must be made, a furnace with a hearth depth of about 10 inches being suitable for both metals.

The alloy is charged into the furnace, melted, and raised to red heat as soon as possible. Zinc shows its presence by a blue flame when the metal is stirred up. In order to prevent oxidation of the other components, the metal should be puddled steadily and sharply until the blue flames cease. The metal is then cooled, first by putting out the fire and admitting an air blast, and then, after the temperature has fallen to 500° F., by shutting off the air and cooling normally. A crust, which contains practically all the copper, now forms on the metal.

The High Copper Crust. The liquid white metal is tapped from under the crust and the latter "dried" by reheating slowly to set free much of the softer metal trapped therein. This soft metal, however, contains much copper and must be added to the next charge. These crusts are accumulated and liquated again, the hard portion obtained this time containing about 40-50 per cent copper, very much antimony, and some tin. The lead is not over 3-4 per cent usually, and may be used for making low-lead bearing alloys.

Melting Pot Treatment.—Steaming. The white metal is now free from zinc and iron, and contains a little copper. Further treatment takes place in the melting pot.

To produce good fine-grained type-metal, the alloy must be steamed in the pot. This may be done by admitting water under a head of 45 ft. a few drops at a time from a pipe running to the bottom of the pot. The alloy is steamed for about 10 minutes and then poured into molds. Cold water is then poured over the molds to produce the fine-grained structure desired.

Further Treatment.—Fluxes and Alloying. If the fracture is not fine-grained enough, even after 5 minutes additional steaming, satisfactory results may be obtained by throwing in a few sticks of sulfur and stirring the bath vigorously with a green pole. After skimming off dross and slag, the pot is steamed for 1 min. and then air blown in for 3 min. The alloy may also be cleaned with hydrochloric acid,

which soon ruins the flue, or with ammonium chloride, which is harmless.

Tests for the Presence of Zinc. The works test for zinc consists in pouring a sample into a deep mold and dragging a card over the surface. The amount of skin immediately formed increases with the zinc content; traces of skin, however, may be formed by copper. Judgment of zinc by skins hanging from the lip of the ladle is not reliable as copper here gives the same effect as zinc.

A reliable method is the following one. To a small sample add an equal amount of antimony, stir with a wooden stick and pour. Copper without zinc is indicated by a yellowish coloration of the solidified surface but if zinc is also present, the surface is shining white.

Making Solder Alloys. For solder containing less than 50 per cent tin, virgin metals are unnecessary, as bearing metal scrap may be converted into "tin alloy" containing 55-58 per cent tin, less than 3 per cent antimony, less than 0.2 per cent copper and no zinc (Abs. 186). Directions are given for casting solder sticks and for making a powdered tin alloy.

Making a High Copper White Metal. In making antifriction alloys containing Sn, 75-85; Sb, 10-15; Cu, 4-10 the copper must be added in the form of a tin-copper or antimony-copper alloy containing about 25-30 per cent copper. The alloy is made by melting the required amount of copper in a crucible furnace, adding antimony or tin and pouring the mixture into the liquid white metal while stirring vigorously. If the hard alloy described above, obtained in purifying white metals does not contain over 4 per cent lead it may be used after reducing its melting point by addition of tin or antimony.

The Production of Remelted Zinc. The remelting of zinc is described and precautions are given for reducing to a minimum, the amount of iron absorbed from the walls of the melting pot. Steel pots containing 2 per cent manganese last twice as long as those of cast iron. Iron may be removed by sulfur.

Refining Scrap Lead. While lead refining is really the sphere of the reverberatory furnace it is possible to do it economically in the melting pot. The field for the melting pot, however, is narrow, very impure or high-tin scrap cannot be refined in this way. The scrap should not contain over 3 per cent antimony and 0.25-0.75 per cent tin. The refining should be done in lots of at least 8-10 tons. The metal is brought to a red heat and then steam and air blown in. Details of

the process and directions for sampling are given, also treatment of the antimony slag obtained in the process.

185. **The Treatment of Metal Residues and Scrap. 2. The Treatment of Tin Residues.** E. R. Thews, *Metal Ind. (London)*, 27:453-455 (1925). 1 Figure.

The reverberatory furnace is replacing the blast furnace for the treatment of tin residues (ashes, slags, etc.) and chemical and electrochemical extractions are also being applied.

The disadvantages of the blast furnace are: the large loss of tin (15-20 per cent); the product contains more iron than tin; the powdery material, if in large amounts, must be slagged or briquetted; charcoal must be used, as coke produces brittleness. The blast furnace gives good separation of lead, copper, antimony, and tungsten, but with intelligent handling, equal results may be obtained with the reverberatory furnace, even using very impure raw materials.

Construction of the Reverberatory Furnace. The construction of reverberatory tin furnaces is described. A cellar should be built underneath, for tin at high temperatures tends to go through the finest joints. The working door should be as near as possible to the entrance flue. The author advises an iron working door with two holes which serve both for the attachment of a lifting fork and for observation of the furnace interior. Two firing doors should be provided. The ash-pit should hold about 5 inches of water. The steam generated in the ash-pit will help to cool the lower side of the grate and the hydrogen formed by dissociation of the water will burn above the fire and increase the heat of the furnace.

A small melting pot is placed under the tap hole of the furnace. After this is filled with metal, a steel hook is inserted, and when the metal solidifies it is lifted out by the hook and transferred to a larger pot, for refining.

Treatment of Dross, Skimming, Etc. Residues containing more or less of metal are first treated in melting pots or liquating furnaces in order to extract as much metal as possible. If they contain much sulfur, arsenic, iron, copper, or antimony they are subjected to combined liquating and roasting on the inclined hearth of a reverberatory furnace. The heat is raised until a powdery residue remains which is added to tin ores or ashes. Residues rich in iron should be smelted with siliceous materials to remove iron, which combines with the silica and is slagged.

Preparing the Ashes for Treatment. Residual tin ashes usually consist of the oxides of tin together with a small amount of metal and impurities. The addition of a slagging material is rarely practiced. The use of sodium carbonate is not to be recommended at all. Except for producing a somewhat more liquid slag it does nothing but corrode the furnace lining. If much iron is present it is slagged by adding siliceous materials, preferably tin ores.

The ashes are mixed with 12-20 per cent of finely ground anthracite, moistened and charged into the furnace to a depth of about 4 to 6 inches.

Working the Furnace. The working doors are closed and luted and the temperature raised to about 2000° F. for about one hour, then rabbled thoroughly, spread out and heated another half hour, etc. The metallic tin should not be stirred up any more than necessary. Before rabbling, two or three shovels full of ground anthracite are spread over the charge to make up for the carbon oxidized. The furnace atmosphere must be reducing throughout the process. The tap hole should be closed except when drawing off the metal. The average time of treatment is 3 to 4 hours.

Usually no trouble at all is experienced with tin ashes of ordinary purity if the temperature is kept high enough. If the slag is very tough, a little fluorspar will soften it. The slag retains a relatively large amount of tin and tin compounds. It is accumulated and liquated, ground anthracite is added to the residue to reduce the remaining metallic compounds.

"Tin Ashes" from Lead Refining. These rarely contain more than 3 to 5 per cent tin. If tin is to be extracted with the lead, comparatively high temperatures must be used with a consequent large loss of lead by fuming. The resulting product is a good base for type metal, etc. Better results are obtained by separating the tin from the lead, keeping the temperatures below 1700° F. with a neutral or lightly oxidizing atmosphere. The product is 99.3-99.5 per cent pure lead, while the residue contains tin oxide which is reduced together with tin ashes.

Treatment of Recovered Metal. The tin produced is never pure, that from mixed ashes is really an alloy of lead and tin. With tin up to 20-25 per cent these alloys may be used for making low-tin alloys after freeing from copper, iron and zinc, while those containing from 25-70 or 80 per cent tin are used for making "tin alloy", a base for solder.

If the product is mainly tin, it is liquated in a reverberatory fur-

nace to remove most of the copper and iron; the lower the liquation temperature, the higher is the quality of the product. If the antimony and lead contents are to be reduced the metal is brought to red heat and puddled under oxidizing conditions. If zinc is present it is removed completely at the same time.

Refining in the Melting Pot. For the final treatment of tin, iron or steel melting pots are used. Their depths should be about equal to their diameters. The pots are filled to about 8 inches of the rim and heated until on removing dross a steel blue skin forms on the surface. The pot is then covered with a perforated iron sheet and the metal poled with a fresh wood pole. The metal is stirred up violently by the gases evolved and lead, antimony, bismuth, and arsenic are oxidized and separated as dross. Sulfur compounds are decomposed while the oxides and sub-oxides of the nobler metals are reduced to the metallic state.

After poling, the tin is cooled to about 500-550° F., at which temperature it remains for about 2 hours in order to permit the settling of arsenic, iron and copper which have formed alloys heavier than tin.

The metal is ladled out, taking care not to stir it up. The lower and more viscous impure layer remaining in the pot is again liquated and boiled.

The degree of refining will rarely attain that of virgin tin. Antimony and lead cannot be entirely eliminated. Further refining is possible only by chemical and electrochemical means.

186. Production of "Tin Alloy" from Bearing Metal Scrap. E. R. Thews, *Continental Met. & Chem. Eng.*, 1:134-136 (1926) and 2:9-11 (1927). [Abstract in *Chem. Abstracts*, 21:1246 (1927).]

"The eutectic relationships obtaining in cooling the mixed metal scrap are described and two processes given whereby the separation of a standard tin-lead alloy at 182-184° C. is obtained. The most marked breaks in the cooling curve occur at 290-300°, 238-240°, and 182-184°. One method of separation in common use is the employment of a rising temperature and the separation of the eliquated alloy in a small reverberatory furnace, while the second method operates with a falling temperature using 10-ton melting pots. The first crystals rise to the top and are skimmed off by means of perforated ladles. The density of the alloy separated increases until finally crystals form on the sides and on the bottom. At 184-183° C. the rate of crystallization drops rapidly and the liquid melt is removed from the pot, pre-

heated hand ladles being used. This metal constitutes the desired alloy. An alternative preliminary process whereby most of the copper and all of the zinc are removed by heating the scrap metal in 5-15 ton lots to a temperature of 800-900° and then cooling is described. The solid first separating out on top contains the copper and zinc. The modern reverberatory process includes this process, and the alloy of approximate composition Sn, 55; Pb, 40; Sb, 3.5-3.8; Cu, 0.1-0.2 separates out at 184° C".

187. Reclaiming Bearings at the Great Northern Shops. F. W. Curtis, *Am. Machinist*, **65**:519-520 (1926). 4 Figures.

The Great Northern Railroad has developed in its St. Paul shops a department for reclaiming bearings. The first step in reclaiming a bearing is to melt the worn lining from the brass in a melting furnace. The bearings are fed intermittently, two at a time, into the furnace. The steel floor of the furnace is perforated so that the molten lining metal drops through. The temperature of the furnace is about 650° to 750° F. About 15 tons of brasses can be handled in 8 hours.

The molten lining metal runs out of a spout at one end of the furnace into molds on a truck, while the brasses are ejected at the other end, where they are inspected while still hot. Rejected brasses are remelted and cast into new ones, which are bored and faced in the Newton car-brass boring machine.

Previous to lining, the brasses are preheated, acid-brushed and tinned according to standard practice. The brass is then clamped to a babbitting fixture, and babbitt poured in from a ladle. The arbor of the fixture is water cooled. Each operator relines an average of 180 brasses per 8 hours, including visual inspection.

The bearing surfaces are finished on a Morton journal bearing miller.

188. Bearing Lubrication as a Basis for the Choice of a Bearing Metal. E. Falz, *Verkehrstech.*, 1927, p. 858. (Abstract by Przygode.)

The author classifies states of lubrication as dry, semi-dry, liquid and semi-liquid. The first two states are rather rare in actual practice. In starting rolling stock, the semi-dry state obtains at first but soon changes to the liquid one. Longitudinal grooves may prevent complete liquid lubrication. Imperfections in the surfaces of journals and bearings may have the same effect. To reduce friction, bearings are some-

times run-in using graphite lubrication, but careful fitting of the surfaces and the use of high-grade bearing materials with low coefficient of friction is to be preferred.

189. Non-Adjustable Cast Iron Bearings. W. M. Byorkman, *Am. Machinist,* 34:203-204 (1911).

The superiority of cast iron as a material for bearings is generally accepted, but few manufacturers have the courage to use them in their products.

The author gives illustrations of some polishing and buffing machines at the Underwood Typewriter Company. The bearings of these are nothing but reamed pieces of cast iron, but so fitted as to insure perfect alignment of shaft and bearings. Provision is made to prevent overstraining the belt and consequent undue load on the spindle.

The plant has had about 100 machines in constant use, some of them for a period of six years. There has been only one case of bearing trouble and this due to the failure to supply oil. In no case has there been any call for adjustment due to wear. The spindles were of unannealed steel ground to a suitable fit.

190. Cast Iron Machine Bearings. R. K. Le Blond, *Am. Machinist,* 34:537-538 (1911).

The R. K. LeBlond Machine Tool Company has found by experience that babbitted lathe bearings stand up better than bronze ones. One lathe with babbitted bearings and a 60 C Midvale steel spindle was in constant service for 12 years, after which the wear of the bearing was only 0.002 in.

This company built four experimental lathes with: (1) bronze box and soft spindle, (2) bronze box and hard spindle, (3) babbitt and soft spindle, (4) cast iron box and hard spindle. The soft spindle is a 60 C crucible steel and the bronze a Pennsylvania Railroad bearing bronze.

The soft spindle and bronze were scratched and both wore considerably, the hard spindle and bronze were in much better condition but the boxes were scratched, the soft spindle and babbitt were in good condition and showed a little wear, the hard spindle and cast iron box were in as good condition as when placed in the lathe and showed no wear. All were oiled in the same way and treated exactly alike.

If a bearing is run dry, a bronze box and soft spindle stands more

abuse than a cast iron box and soft spindle, but less than a cast iron box and hard spindle.

The author states that in general the bearing surfaces working together must be of dissimilar metals, the only exception being cast iron and cast iron which will make satisfactory bearing. It is practically impossible to lubricate a bearing with both surfaces of soft steel so that they will not cut. Soft steel and bronze is the next poorest. Soft steel and cast iron will give good service if properly lubricated but will not stand the slightest amount of neglect. Soft steel and babbitt is as near foolproof as any combination, while hard steel and cast iron will stand as much neglect as anything, will last much longer, and will stand intermittent cuts or a series of blows which would peen out or loosen babbitt.

Soft steel and cast iron is all right if the cast iron has been glazed. However, once the shaft starts to cut, the results are disastrous. The author gave one such example where the cast iron box was practically powdered.

191. **The Manufacture of Railroad Bearings in Australia.** Anonymous, *Brass World*, 5:231-233 (1909).

An article descriptive of the work at the Norman Brass Foundry, Brisbane, Queensland. A new form of car bearing has been developed which is destined to become the standard in that country. The bearing is made in two parts, a lining of bearing bronze and a back of cheaper metal, such as cast iron. These two are held together by running in babbitt metal between them. The advantage of this construction is that the liners may be stocked and replaced when desired, and the old backings used over again. Twenty bearings may be relined per hour.

It has been found in Australia from a series of tests that bronze bearings are best adapted for the weights of cars used there. They stand end thrust better than those of other metals tried. The babbitt used for joining lining and back is Pb, 85-80; Sb, 15-20. Details of manufacture are given.

192. **Railroad Bearings, Their Design and the Alloys Used in Their Production.** G. H. Clamer, *Brass World*, 10:43-49, 83-89 (1914).

The author gives some statistics on the amount of bearings in use, and produced per year. He traces the development of railroad bear-

ings from 1872. Previous to this, no standard bearing existed and there was great confusion. In this year the Master Car Builders' Association adopted a standard form of bearing, the MCB, which is of the same general type as present ones. The weight of cars, bearings, and load per bearing has steadily increased since this time.

The MCB bearing is defective in the following respects: (1) It embraces too much of the journal, leading to frequent rupture of the oil film, though this large bearing surface is claimed to be necessary to take the brake pressure. However, the use of side pieces would be better.

(2) It has not the maximum strength for the amount of metal.

(3) It is too rigid in the box.

The MCB has 10 per cent excess weight, meaning 30,000,000 pounds of excess metal in service.

Sanderson has designed a brass bearing which is 12 per cent lighter than the MCB, and which is about the light-weight limit for the bearing alloys ordinarily used. The author and Hopkins have designed a bearing which represents the extreme limit of reduction of the MCB, but a stronger alloy must be used (Perfecto Bearing, made of Ajax Perfecto bronze). This stood up better than an MCB of Ajax Plastic bronze, especially in the transverse test.

The author traces the development of bearing metals. Hopkins in 1870 patented a bearing lined with Pb which was attached to the shell by tinning. The difficulty with breaking in a new bearing was almost completely overcome. In 1887, Dicks in England produced the well-known "S" phosphor bronze; Cu, 78-80; Sn, 9-11; Pb, 8-11; P, 0.7-1. In 1890 the Ajax Metal Co. produced an alloy practically the same as Dicks', except that no P was added, as an excess of phosphorus above that required for deoxidizing was found to be detrimental. Brittle phosphides are liable to be formed, leading to rapid wear and heating. One disadvantage of phosphor-bronze is the narrow range of temperature within which it must be poured.

The author reviews Dudley's experiments leading up to his Ex. B alloy. Dudley's conclusions were: (1) that wear and heating decreased with Pb; and (2) increased with Sn content. His Ex. B alloy Cu, 77; Sn, 8; Pb, 15; P, 0.25. The reason he could not add more lead was because the P present kept the alloy liquid a long time and allowed the Pb to segregate.

Clamer and others experimented further by omitting the P and using very pure materials. They arrived, finally, at Cu, 65; Pb, 30;

Sn, 5 (Ajax Plastic Bronze, "A" Grade). Compositions between this and Ex. B tested on a Carpenter friction machine confirmed the laws established by Dudley.

Zn is a detrimental impurity as it increases the amount of wear and tends to segregate the Pb. However, enormous tonnages of bearings contain up to 10 per cent Zn, and give good service, because there is usually enough Pb to offset the disadvantages of Zn. The author gives a table of specifications of bearings of American railroads.

Hopkins, during the life of his patent, used only pure Pb, as thin as it was possible to cast it, or even sheet Pb sweated to the back. Although he only designed the bearings to be self-seating, good mileage was obtained before the linings wore through. As the thickness of the lining was increased, it became necessary to harden the Pb to prevent squeezing out. Many roads have increased the thickness up to five-sixteenths in. so that practically the entire operation is on the lining only. Some bearing metal specifications are given. Composition and heat treatment or of vital importance. (*Cf.* Lynch's paper.)

It is fairly well established that the harder the alloy, the greater is the tendency to heat, the higher is the rate of wear, the lower is the coefficient of friction, the less is the abrasion of the shaft and the less the tendency to distort.

For a three-sixteenths in. lining, Pb, 95; Sb, 3.5; Sn, 1.5 may do, but for a five-sixteenths in. lining, an alloy such as Pb; Sb, 10-20; Sn, 3-5 is necessary.

193. U. S. L. Self-lubricating Bearing. Anonymous, *Am. Machinist*, 60:903 (1924). 1 Figure.

This bearing consists of a shell of hard maple impregnated for service with a suitable lubricating oil. Grooves are cut in the shell and babbitt is cast therein. The inside is then reamed to proper size. The babbitt reinforcement adds to strength and durability and decreases the effect of atmospheric moisture.

194. New Bearing Said to Eliminate Need for Reaming or Broaching. Anonymous, *Automotive Ind.*, 51:247 (1924).

Line-reaming or broaching crank shaft main bearings is claimed to be unnecessary in the case of a new bronze back babbitt lined bearing known as the close limit interchangeable type developed by and patented by the Federal Mogul Corporation.

The bearing is pressed or sprung into slightly elliptical shape before

splitting, and the cut taken along the major axis of the ellipse. The diameter at the split is 0.004-0.005 in. greater than if the shell were cylindrical. The halves are held in a cylindrical fixture (sprung to circular outline) and the finish broached, with a very light cut. The tolerance on the inside, outside diameters and thickness is 0.00025 in. The upper half is sprung into its seat in the crank case, and the lower half is held by dowels, to prevent the whole from turning.

Of course use of these bearings involves very accurate aligning of the bearing seats.

195. Olds Uses Novel Production Method for Interchangeable Bearings. W. L. Carver, *Automotive Ind.*, 52:978-981 (1925).

Interchangeable bronze back, babbitt lined bearings which can be installed in engine assembly work or in the dealers service department with no further treatment are produced in a separate department at the Olds Motor Works. The machining tolerances are so close that any individual bearing will fit when inserted in the engine with no need of fitting or scraping. Details of the machine work are given with 7 illustrations.

The shells are centrifugal cast of Cu, 85; Pb, 8.8; Sn, 5.4; Zn, 0.8, then machined, acid dipped and tinned in a gas furnace at 625° F. (330° C.). Babbitting is done by centrifugal casting in a speed lathe, the babbitt (Sn, 85; Cu, 7.5; Sb, 7.5) being introduced through the tailstock spindle. After leveling off and allowing flotation of dross, the shell is rotated at 900 revolutions per min., and an air blast turned on, inside and out. A very dense babbitt is produced which is free from blowholes and only a small fraction is thrown out for defective bonding. Details of the subsequent boring, broaching, burnishing and swaging to contour are given.

196. Some Limitations of Oil Ring Bearings. E. G. Gilson, *Am. Machinist*, 63:1005-1007 (1926).

Oil ring lubrication is satisfactory at low speeds, but analysis shows that there is a limiting speed which cannot be exceeded.

A bearing is nothing but a heat generator, and if the heat is not carried away the oil will oxidize and sludge with consequent unsatisfactory performance.

Heat is generated by the internal friction of the oil and this in turn is influenced at high temperatures by the metals of the bearing.

Oil is more important as a lubricant at low speeds, and as a remover of heat at high speeds.

The greater part of the heat can be removed by rapidly replacing the oil film, i.e., by forcing large quantities of oil through the bearing.

The factors which most seriously affect the oil flow are: (1) the oil ring; (2) grooving of the bearing. Performance of the oil ring is not ideal, slippage on the shaft being great. In fact, with increasing shaft speed a point is reached where there is no further increase in speed of the ring, but this may even decrease in speed or actually stop. Also as the speed increases, more of the oil clinging to the ring is thrown off by centrifugal force reducing the amount of oil supplied to the journal to that carried by the inner face of the ring, an amount which depends upon the surface tension of the oil. The oil is squeezed off of the ring before it reaches the highest point (point of contact with shaft), which is 90° ahead of the oil ring slot, where most bearing grooving systems start. On the other hand, if the grooving should start at the top of the bearing the oil would not enter it. Observation shows that most of the oil which actually reaches the entrance of the ordinary grooving system does not enter the bearing but merely piles up and flows down the outside of the shell or bushing. The reasons for this are: (1) centrifugal force; (2) oil film pressure at this point is greater than atmospheric so that the flow should be out of instead of into the bearing. The only oil entering at this point is that which adheres to the shaft, and while sufficient to lubricate the bearing at low speeds, it is not sufficient to cool the bearing at high speeds. However, there is usually a small portion of the oil film where the pressure is below atmospheric and the oil flow from the ring should be connected to this region.

A typical oil film pressure distribution chart is given. The author shows how by proper grooving the oil pouring down at the usual point of entry, 90° from the top in the direction of rotation, can be carried around to the low pressure sector. If this is done, the difficulty will be to carry enough oil to the bearing with the oil ring.

The author admitted oil to a bearing at each of a series of tap holes along the top side of the bearing and found that the flow was greatest in the region where the pressure was lowest.

The region of low pressure may be used to pump oil directly from the oil well into the bearing. Unfortunately it is rather hard to locate this region. It seems to be about 120° in the direction of rotation beyond the point of nearest approach of journal and shell, the situa-

tion of which is influenced by many factors. It is not necessary to find this point of minimum pressure accurately, however. Practically worthless bearings have been made to give satisfactory service by grooving so as to lead the oil into the low pressure region.

197. The Pad System Applied to Journal Bearings. Maj. F. Johnstone-Taylor, *Am. Machinist*, 60:9-10 (1924). Figures.

Clearance of ordinary bearing brass must be so large that only part of the oil film is effective. A bearing using pivoted pads ground exactly to the radius of the shaft has nearly the whole bottom half of the journal supported on the oil film. The author claims that the bearing can support ten times the load of the ordinary journal brass. The pads are lined with white metal.

198. Locomotive Bearings. G. R. Henderson, *Trans. Am. Soc. Mech. Eng.*, 27:420-422 (1906).

The extreme length possible over bearings is limited by the track gauge, while other design factors prevent drawing the frames closer together. The practice of providing extra bearing surface by extending the inner side of the bearing is sometimes resorted to, but is not to be recommended as it imposes an eccentric load on the journal.

For instance, if a box is increased in length from 10 to 12 inches, while the spring saddle remains in its original position, 5 inches from the outer end, the center of load no longer coincides with the center of length and the unit load at one end is three times that at the other. The results of this are often overheating or uneven wear. It would be better to use a shorter box and keep the center of load coincident with the center of length.

199. The Application of Babbitt Metals. L. D. Staplin, *Am. Machinist*, 54:15-16 (1921).

Bearing troubles are often caused by faulty alignment and grooving. Examples are given of good and bad grooving. All grooves should have rounded edges, as sharp edges act as scrapers and destroy the oil film. The ends of bearings should be rounded also. Groove as little as possible, as this reduces the load supporting area. Make the anchoring deep enough to hold well. Even with correct anchoring, soldering or tinning may be advisable.

Guard against overheating the metal, mandrel or shell to avoid looseness. Overheated metal has a more open structure and packing

results when it is loaded. Pour at as low temperature as possible and warm the mandrel only enough to remove the chill. The desired structure may be obtained by quenching in water after casting. Overheated metal develops small cracks after short service and finally the metal gives way. The results of overheating are not so severe with a lead base as with a tin base babbitt.

200. Bearings and Bearing Metals. C. H. Bierbaum, *Machinery,*
          29:298-300 (1922).

The author's conclusions are, that for properly designed, constructed and lubricated bearings:

(1) The bearings surfaces are completely separated by a film of oil. (2) The friction of operation is the fluid friction in the oil film, an adequate thickness is essential. (3) Proper clearance should be allowed for the normal thickness of the oil film. (4) The advance edge of the bearing must be rounded or chamfered to permit the oil film to form. (5) The oil film forms most effectively on the surface whose advance edge is at right angles to the direction of motion. (6) An increase of speed increases the thickness of oil film, clearance permitting. (7) An increase in viscosity increases the thickness of the oil film. (8) The larger the unbroken area of oil film, the greater the load supporting capacity. (9) Every unnecessary oil groove reduces the supporting capacity. (10) For every bearing condition there is a thickness of oil film corresponding to maximum efficiency.

Caution: Do not drive bushings too tightly, the clearance will lessen when they become heated.

The author gives notes on machining and grinding.

201. Ways to Cure Sleeve Bearing Troubles. R. Pruger, *Ind. Eng.,*
          82:113-117 (1924).

This article discusses the design and maintenance of bearings for electrical machinery. The air pressure must be balanced where there are several bearing seats. The suction of the blower may draw the oil from one chamber to the next if the cored holes are submerged in the oil. Westinghouse motors have the coring in a connecting channel at the top of the housing. Foaming oils are cautioned against. Points on high speed machine bearings are given. Illustrations are given showing the evolution of the leak-proof bearing housing.

The advantages of sleeve bearings are: there is a large bearing

surface, the oil film forms a flexible or cushion element, and the babbitt lining after being run-in conforms to the load conditions.

Replacements, heating, and operating expenses are discussed.

202. **Causes of Babbitted Bearing Failures.** L. D. Allen, *Am. Machinist*, 64:754 (1926).

Most failures can be traced to one or more of the following causes:

(1) Excessive loads gradually crush the liner. (2) The bearing, not finished to obtain smoothness, will heat and wear. (3) There is poor alignment. (4) The bearing is keyed too tight. (5) The lubricant is too thick or too thin. (6) The wrong grade of babbitt is used. Babbitt should be bought not by formula but by the service required. (7) The metal is poured at the wrong temperature. High tin alloys should be poured at 700° F. (371° C.) and high lead ones at 800°-900° F. (426°-482° C.). (8) Grit and foreign matter are present.

203. **Critical Phenomena in Plain Bearings.** C. Hummel, *Z. ver. deut. Ing.*, 71:379-382 (1927). 13 Figures. (Abstract of *Ver. deut. Ing. Forsch.*, No. 287, "Critical Speeds of Rotation as a Result of the Yielding of the Lubricant in the Bearing". Berlin, 1926, pp. 48.)

"According to the generally accepted hydrodynamical theory of bearings, critical states are to be expected in every plain bearing. In opposition to the original conception of a shaft climbing up the bearing in the direction of rotation, which is valid for unlubricated bearings, the hydrodynamical theory pictures to us a shaft floating in the lubricant, whose load is taken up by the upward pressure of the lubricant. This, under given operating conditions (dimensions of shaft and bearing, angular speed, loading of shaft, viscosity of lubricant), is a function of the relative position of the shaft and the bearing.

"The equilibrium position of the shaft may be stable or unstable. In the first case, the shaft if slightly disturbed will oscillate back into its equilibrium position; in the second case this does not occur and the equilibrium is permanently disturbed. If the equilibrium is stable, the shaft has two periods of free vibration as it can vibrate either horizontally or vertically, hence in two directions. If external periodic forces of the same frequency as those of the free vibrations of the shaft act upon it, resonance occurs and the amplitude of vibration of the shaft becomes greater and greater, until the inevitable damping permits no further increase. Even though the amplitude does not

actually become infinite, it becomes so great that any controlled operation is impossible. We have, therefore, to do with a critical speed of rotation. In order to find this out and to overcome it we will start from Reynolds' theory of the plain sliding bearing".[800]

The problem of determining the oil pressure in a half bearing is solved, making the usual assumptions that the inertia forces are negligible and that the clearance is small compared with the radius. The pressure is integrated over the bearing surface to give the horizontal and vertical components of the force on the shaft. These values are plotted for all possible positions of the center-line of the shaft.

Strictly speaking, these computations do not apply to the ordinary journal bearing, because some of the assumptions made, *viz.*, uni-dimensional flow, constant viscosity, and fixed center-line of shaft are not valid here. A graph is given for making the correction for the finite length of the shaft.

The equations of motion of the shaft are next set up and solved, giving the displacement components of the shaft, x and y in the form:

$$x = A\,e^{i\lambda t} \qquad\qquad y = B\,e^{i\lambda t}$$

where A and B are arbitrary. If λ is real the equilibrium is stable, while if λ is complex, the equilibrium is unstable.

Let ω be the frequency of the unbalanced centrifugal forces acting on the shaft, it is a critical frequency if equal to λ. A graph is given of critical speed plotted against the parameter

where:

$$\Gamma = \left[\frac{\bar{p}}{\eta}\left(\frac{\delta}{\gamma}\right)^2\right]^2\frac{\delta}{g}$$

p = average vertical pressure over bearing.
η = viscosity of lubricant.
δ = difference in radii of bearing and shaft.
γ = radius of shaft.
g = acceleration of gravity.

$$p_{v}' = \frac{\delta^2}{\eta\omega\gamma^2}\bar{p}$$

If $\Gamma > 30$, corresponding to $p_{v}' > 3.5$, the equilibrium of the shaft is stable and there are two critical speeds, while if $\Gamma < 30$ the equilibrium is unstable only.

"In order to test the foregoing deductions, a heavy shaft on which was mounted a flywheel was driven by a variable speed motor through two universal joints. The bearing was a purely radial one, the lower half, of phosphor bronze, was smooth with a sharp leading edge, the

upper had a clearance of several millimeters, thus realizing the case of the half-bearing. The bearing was lubricated by a drip oiler that allowed one or two drops of oil per second to fall on the shaft".

By means of an optical system the vibrations of the shaft could be thrown on a screen. Four photographic records are given. A plot is given of the amplitude of vibration of the shaft against the speed of rotation. Two critical speeds are plainly shown, for which the amplitude rises to three times the value which it has between these two speeds. The transition from stable to labile equilibrium is also shown.

These critical phenomena may be overcome in practice by shaping the bearing surface to obstruct the vibrations. As, however, friction would increase at the same time it will be more correct from an operating standpoint to so design the bearing that the region of critical phenomena will be avoided.

204. Hot Bearings. E. Kistinger, *Machinery*, 14:141-144 (1907).

The author states that the main reasons for hot bearings are: (1) shrinkage or contraction of the babbitt; (2) shrinkage strains set up in the babbitt liner by unequal distribution of the babbitt over the shell; (3) a lack of contact between the babbitt and the cast iron or steel shell; (4) partial deflection of the lubricant into the wrong place.

Assuming perfect contact between the babbitt and the shell at the temperature of solidification, the babbitt will tend to loosen on cooling as most babbitt metals have a coefficient of expansion about two or three times that of cast iron or steel. The fact that most bearings are split does not affect the result. If the babbitt is secured by mechanical anchoring, such as dovetail grooves, shrinkage strains will arise. Shrinkage, of course, also takes place in the axial direction, or shrinkage strains if lining is anchored. Such strains may start cracks after the bearing is placed in service.

Some parts may be in worse contact than others due to gas bubbles. This is especially liable to happen in babbitt containing copper. The common practice of peening is very questionable as it is liable to drive bubbles from a place of bad contact to ruin a place where the contact is good. The bearing metal also becomes brittle and minute cracks start which enlarge in service. Peening has been discontinued on the continent.

The hollow space due to shrinkage is bound to become filled with oil and as the thermal conductivity of oil is only about one two-

hundredths that of cast iron or babbitt, the heat generated is carried away much more slowly than if metallic contact existed. The hydraulic pressure of running also tends to produce cracks in the liner. Both these factors tend to ultimate overheating and destruction of the liner.

Two bearings were tested by the author under a load of 400 pounds per sq. in at 480 ft./min. One in which the metallic contact was good ran at 60° F. over room temperature, while the other, in which the bonding was poor, ran at 85° F. over room temperature. The usual working conditions in engines are much worse.

The author describes the Glyco bearing, a skeleton bearing designed to eliminate some of these difficulties. An $8\frac{1}{2} \times 15\frac{5}{8}$ in. bearing had a skeleton of 10 gage soft steel perforated plate, secured to the cast iron shell by countersunk screws, while the bearing metal proper was Glyco metal. The thickness of the lining may be reduced due to the strength of the steel reinforcement, sometimes as much as 50 per cent. The skeleton may be cast with the back by placing it in the mold, the holes, of course, being filled with sand.

205. What Foundrymen Can Do to Prevent Hot Boxes. R. R. Clarke, *Foundry*, 45:111-114 (1917).

The author warns against certain foundry and shop practices which, however, it would seem to be almost common sense to avoid.

He states that too many junk bearings and zinc contaminated bearings are in service.

He doubts the wisdom of hard particles in a softer matrix for anything so severe as railroad service.

Cautions are given regarding the use of scrap and of overheating in melting. Sources of porosity are: overheating, chilled mandrel, and steaming back. (The back sometimes retains water from the quenching even after boring and tinning.) Inclusions of oxides will produce a similar effect.

The loosening of the lining from the back may be due to: dull boring tools, poor tinning, the pouring temperature being too low, steaming back, oxidized tin surface, rough handling in hot or cold condition. He cautions against buffing the surface on an emery wheel, as particles of emery may be embedded in the metal.

The author criticizes the railroads for using bearings, just as they come from the mandrels, except for rough trimming edges and ends, for all purposes but engine truck and trailer brasses.

206. Eliminating Cracking in Bearing Metals. Ch. Vickers, *Foundry*, **51**:581 (1923).

A manufacturer had trouble with the cracking of a bearing alloy: Pb, 88-85; Sb, 8-10; Sn, 3-5, which was required to stand 70,000 lbs. Vickers advises him to increase the Sb content to 15 per cent and pour at the proper temperature, *viz.*, 625° F. (330° C.). The metal will char a stick of wood at this temperature but will not cause it to flame.

207. Recent Developments in Aircraft Engines. L. M. Woolson, *J. Soc. Automotive Eng.*, **16**:122-125, 297-309 (1925).

The author traces the development of the Packard aircraft engines. The foundation of the engine design is the bearing layout. The life of the main and connecting rod bearings is important in determining the length of time between overhauls. The past practice, in allowing large factors of safety, is not altogether satisfactory. If followed, we are denied an important means of reducing weight, namely by reducing the length of the bearings and thereby the length of the engine. The limitations of close cylinder spacing are eliminated by the Packard design. The failure of aircraft engine bearings has rarely been caused by lack of lubrication or by wear, but usually by cracking or crushing of the babbitt lining after 30-150 hours of service. Failure is frequently caused by fatigue of the lining produced by the minute flexure of the backing. Hence if the backing can be made more rigid, greater loads can be carried.

Tests were run on a bearing machine (to seizure under overloads) to determine what the limits of the metal actually were. A table of results is given of tests on the Liberty and the Packard engine, also a table of the maximum and mean operating bearing loads of these engines.

No trouble was experienced with babbitt linings on steel shells. Babbitt will loosen, however, when backed with bronze. The elasticity of the steel is about double that of bronze.

208. Metals for Car and Power House Bearings. H. H. Buckman, *Elec. Ry. J.*, **60**:47-48 (1922). (Abstract of paper presented before the C. E. Electric Railway Association, June 25-30, aboard S.S. *South America*.)

Some of the essential characteristics of a satisfactory bearing metal are given and the advantages of a lead base alloy are discussed. While

bearing metals are essentially the same as those used by Babbitt in 1839, the ability to use increased speeds and loads is due to better lubricants. A relined bearing has rarely more than 75 per cent efficient bonding and this is often as low as 30 per cent, due to the impossibility of getting all of the oil out of the backing. Loose bearings wear faster than tight ones.

209. Babbitt Will Not Adhere. Ch. Vickers, *Foundry*, 51:581 (1923).

A manufacturer had difficulty making babbitt adhere to ground and tinned brasses. Vickers advises machining instead of grinding, as the latter process tends to burr over and bury any oxide, instead of removing it. Solder will not adhere to such a surface. Swabbing with zinc chloride before applying soldering acid (HCl) is advised.

210. The Essential Properties of Sliding Contact and Roller Bearings. R. Stribeck, *Z. ver. deut. Ing.*, 46:1341-1348 (1902).

A study of bearings should not be limited to steady running conditions, which give information more on the lubricant than on the bearing metal. Of much greater importance is the running-in of a journal and the phenomena taking place when starting up. Often hours elapse before thermal equilibrium is attained after starting up, and the friction is generally greater than during steady running conditions.

Running In. All bearings must be run in, as the effect of load cannot be allowed for in machining, also the thickness of oil film is estimated with difficulty. With a hard steel shaft, cast iron bearings can be run in only very slowly, bronze is better and some of the plastic white metals are still better.

The load capacity is greater the easier the bearing is run in, except for cast iron bearings so designed that bending does not occur. Such bearings may carry a heavily loaded hard steel shaft. In general, however, the running in of cast iron will have to be aided by scraping off the high places and increasing the load after each operation. White metals, on the other hand, adjust themselves by yielding, though they must not yield too much. A metal with a yield point of 200 kg./cm.^{2} was found to stand up under a mean load of 90 kg./cm.^{2} Bronzes adjust themselves by abrasion and the shaft is generally worn in the process. In a properly designed bearing, abrasion must stop and polishing occur before the whole surface is attacked, though this

is not possible under some conditions. Of the two modes of running in, that of plastic yielding is more reliable.

Tests to determine the behavior during running in take much time and if made under service conditions, the results will depend more on the lubricant than on the bearing metal.

Lubricant. The character of the lubricant has great effect on the load capacity and reliability, but, for lack of time, the author had to choose one lubricant for all the bearings tested. This was a rather heavy, transparent, fluorescent yellow mineral motor oil. Its Engler viscosity was as follows:

Temperature, °C.	20	30	40	60	80	100
Viscosity	40.5	20.1	10.9	4.61	2.42	1.74

Viscous mineral oils have about the same viscosity at the higher temperatures.

Tests were made at 1100 and 760 revolutions per min. on a Sellers bearing 7 cm. diameter by 23 cm. long, having two oil rings. The shaft was supported by babbitted bearings on either side of the test bearing. Curves are given of the coefficient of friction *vs.* the steady temperature for different loads. Curves of temperature *vs.* time showed that about 3 hours elapsed before a steady state was reached. The coefficient of friction decreased with the time. The work of friction of intermittently used machinery is then underestimated if the value of the coefficient for the steady state is used.

Curves of coefficient of friction *vs.* load are given for different speeds and a constant bearing temperature of 25° C. Each of these curves showed a decided minimum, which occurred at higher speeds, the greater the load. At high speeds a minimum was not reached because the bearing scored first. At higher temperatures, the lower the speed the sharper was the minimum.

The curves of coefficient of friction *vs.* speed for constant load, also show minima, which are more pronounced and occur at a lower speed the lower the load. In all cases the value of the minimum coefficient is about the same, *i.e.*, about 0.0035. Static friction is also about the same, *viz.*, 0.14 for all loads. This is about the same order as that found by Morin for slightly greasy surfaces at low pressures.

The greatest friction is, then, to be overcome on starting, and the higher the speed the better the lubrication, also the higher the ratio of fluid to solid friction.

If the friction is chiefly solid friction the coefficient increases with the oil temperature. Curves are given.

Theory indicates that the coefficient of friction should be decreased on the downward branch and increased on the upward branch of the curve if the diameter is increased. Experiments with a shaft with a variation of 0.1 mm. in diameter increase or decrease confirmed this as far as the upward branch was concerned. If a new shaft is specially fitted to the bearing, the effect is the same as an increase in diameter. This was confirmed rather weakly for the downward branch, and strongly for the upward branch of the curve.

On the rising branch of the curve, the coefficient in general increases less rapidly than the speed, i.e., the slope gradually becomes less. This is due to the thickness of the oil film increasing with the speed.

The author cautions regarding the interpretation of his curves; they are for a bearing temperature of 25° C. In practice the temperature will be higher, the viscosity less, and the oil film thinner. In fact, scoring may occur.

The figures, however, give a basis for predicting the behavior on starting. In this case the friction does not increase so rapidly as indicated on the curve as the oil film is thinner than in the steady state. Moreover, with ring oilers, the lubrication is deficient at low speeds. Another set of curves gives the coefficient of friction vs. speed for a steady state under different loads. Temperatures are given on the curves. The curves have maxima and tend to approach a constant value as the speed increases.

White Metal Bearings. These bearings, lined with Magnolia metal, could be automatically run in, which was not possible with the Sellers bearing. The diameter was 7 cm., length 13.7 cm., yield point of metal was 200 kg./cm.², average bearing pressure 25 kg./cm.², though sometimes as much as 50 kg./cm². Lubrication was by a central oil ring. Another series of tests was made with the length cut to 7 cm. The results were the same as those of the first series at high speeds, but differed at low speeds. Above 64 revolutions per min. and a sufficiently high load the coefficient of friction increases with the load, this state occurring at lower loads for the longer bearing. Results of the second series of tests are given.

The bearing was run in using an American light spindle oil. The speed was 64 revolutions per min. and the load 11.5 kg./cm.² The room and initial oil temperature was 14.5° C. Curves are given of the

coefficient of friction *vs.* time for loads of 11.5, 19.0 and 2.36 kg./cm.^{2} The force became steady after 10 min. when the coefficient amounted to 0.02. A maximum temperature of 25° C. was attained after 45 min. During 14 hours the coefficient decreased continually and reached a constant value of 0.0026, the temperature being 20° C. (2.5° above room). With a load of 19.0 kg./cm.^{2} the final coefficient was 0.0022 at 21° C., while with a load of 26.3 kg./cm.^{2} much larger values of the coefficient were obtained in the latter part of the run, and there was much variation in the force of friction. After 16 hours the coefficient was still 0.006, while there was a period about 10 hours after the start when the coefficient went as high as 0.07. No damage was done, however. On decreasing the load to 19.0 kg./cm.^{2} the coefficient fell to 0.0022. With a load of 36.3 kg./cm.^{2} readings were impossible. After 10 hours' running during which the temperature rose repeatedly to 40° C. the coefficient was 0.003 at 24° C. and the bearing was still not completely run in. If the load was reduced to 25.2 kg./cm.^{2}, the coefficient fell to 0.002 at 24° C. No damage was done. With a load of 43.6 kg./cm.^{2}, the shaft ran 5.5 hours with frequent interruptions due to the belt slipping off and readings were impossible. The bearing squeaked very loudly toward the end, but the surface was merely glazed. The tests indicated that the oil was too thin, but that the Magnolia metal adjusted itself well.

A thicker gas engine oil was next tried. At the maximum load obtainable on the balance, *viz.*, 51 kg./cm.^{2}, speeds of 190 and 380 revolutions per min. were used. The load could be increased to this value in a few hours and the coefficient reached its steady value soon after.

This bearing which was run in with motor oil was next lubricated with spindle oil and run at 380 revolutions per min. under a load of 36.3 kg./cm.^{2} The lubrication was sufficient at this load, but bad if the load was increased to 42 kg./cm.^{2}

Paraffin oil gave the same results as spindle oil at 36.3 kg./cm.^{2}, while the bearing soon overheated if run at 51 kg./cm.^{2} Castor oil caused great friction and heating. Water was valueless as a lubricant, causing great frictional heating and wear.

After the bearing had adjusted itself again, it was reduced in length to 7 cm. Curves of the coefficient of friction *vs.* temperature are given for the 7 cm. bearing. Under loads varying from 0.7 to 76 kg./cm.^{2}, and speeds from 190 to 1100 revolutions per min. the coefficient decreases with both the temperature and the load. Steady running temperatures were not observed. The decrease of the coefficient

with the temperature is most rapid at small loads. The coefficient of friction depends not only on the viscosity but also on the thickness of the oil film, confirming the fact that the coefficient decreases slower than viscosity.

The curves of the coefficient vs. load had flat minima at low speeds, but the minimum is hardly reached at high speeds when the temperature is 25° C., i.e., the curve starts to rise at a much higher load than in the case of the Sellers cast iron bearing.

The curves of the coefficient vs. speed for different loads at 25° C. are given. The static friction is considerably greater than in the case of the Sellers bearing (0.2 to 0.24), but falls much faster with increases in speed. A minimum is not shown for all loads. The lowest value of the coefficient is about 0.0015 for loads over 5 kg./cm.[2]

Another white metal lined bearing of 4.8 cm. diameter gave about the same coefficient vs. temperature curves.

Comparison of Magnolia Metal and Sellers Cast Iron Bearings. In cast iron bearings at low and average speeds faulty lubrication and high friction occur for much lower values of load. At high speeds, however, the coefficient of friction is lower for the cast iron. This is not to be interpreted as proving the superiority of the Sellers bearing. The supporting surface is only part of the whole area. Actual supporting surface may be estimated from the glazed area. It is much smaller for the cast iron bearing. The differences in the coefficient are much less if, instead of taking the average over the whole surface, the unit load on the supporting area is taken, and comparisons made of coefficient for the same values of actual unit load. If the actual unit load for the Sellers is only about half that of the Magnolia metal bearing, the coefficient of friction vs. time curves fall close together.

The load capacity of a poorly fitting bearing is less than that of one which fits the shaft. Frictional losses must be compared for the same total load, not for the same unit loads.

211. Tests of Large Shaft Bearings. A. Kingsbury, *Elec. J.*, 3:464-469 (1906).

The author describes some tests made preliminary to running the 5000 kw. generator of the Niagara Falls Hydroelectric and Power Company. The rotating field of this generator weighing about 100,000 lbs. is designed to run at 300 revolutions per min.

The apparatus used consisted of a horizontal shaft mounted on three bearings, the middle one being pressed against the shaft by

means of a lever. The outer bearings were 9 in. in diameter by 30 in. long and the middle one 15 in. in diameter by 40 in. long. Bearing friction was estimated from the power input to the 150 horse-power direct current motor driving the shaft.

The bearings were lined with genuine babbitt and scraped to fit. The middle bearing had a top and side clearance of 0.03 in., while the other two had vertical clearances of only 0.007-0.008 in., which was not enough to provide for expansion if the rate of heating was too great. The lower halves of the bearing were water cooled.

Bearings were flooded with oil from a small supply tank, the return flow being water cooled. Oil entered a wide and deep groove in the babbitt running nearly the whole length of the bearing.

Due to the small clearance of end bearings, considerable time was necessary to attain full speed. Three hours were necessary to allow the parts to become heated.

The thickness of the oil film was measured under a load of 94,000 lbs. at a succession of decreasing speeds by means of four Bath lathe indicators. Curves are given for readings 45° either side of the bottom point. At all speeds the shaft was displaced in the direction of rotation, confirming the theory of Osborne Reynolds.

The maximum speed attained was 1350 revolutions per min. Below 400 revolutions per min. the speed could not be controlled, and below 300 revolutions per min. lubrication was imperfect so that the friction increased rapidly.

Test data are given for heavy machine oil and paraffin oil.

The author concluded that it was possible to run bearings at loads and speeds far in excess of those obtaining in ordinary practice, even without water cooling. One run was made under a load of 94,000 lbs. at 1243 revolutions per min. with only a small amount of water cooling; the oil supply, however, was cooled.

212a. **Laws of Bearing and Dry Friction Are Similar When the Loads Are High.** P. M. Heldt, *Automotive Ind.*, 49:573 (1923).

The author mentions Stanton's claim to have established the existence of "boundary lubrication" under certain conditions. "B.L." is defined in the work of Beauchamp Tower [789] and the theoretical analysis of O. Reynolds.[800] In general there is no motion of the lubricant relative to the metal at the boundary (slip), but as the load increases the oil film becomes thinner and finally only of molecular

thickness and slip occurs. Earlier investigators regarded this as only the transition from lubrication to seizure. Recent workers have resorted to it, however, to explain the heavy load capacity of certain high friction bearings, as the teeth of heavy duty worm gears, etc. Heldt quotes Deeley's concept of continuous gradation from the steel of the shaft to the metal of the bearing, the surface layers being composed of both oil and metal molecules.

According to the Lubrication Investigation Report,[311] for conditions of boundary lubrication the value of a lubricant does not depend wholly on the viscosity as many thick lubricants will not prevent wear, while others will. "Oiliness" must be regarded as an important property of the lubricant. Under many conditions bearings run entirely separated; under others, not. The author refers to the work of Deeley[880] on the friction of round pins sliding on plates. Deeley concludes that static friction varies not only with the oils but with the metals used. He claims it is possible for the oil to penetrate the metal for a considerable distance, forming a mixture or compound which acts as a lubricant. Oily liquids are those which enter into combination with the surface molecules of the metal. He cites experiment of trying to file with an oily file in which the cutting power is greatly decreased by the oil. One conclusion is: "In general engineering practice the lubrication of all machine details where the relative motion is of reciprocating character may be taken as boundary lubrication".

Stanton's experiments with an oscillating shaft are cited,[835] in which he concluded that the lubrication was of the boundary type. Time vs. deflection curves were straight lines as in the case of dry friction. (The speeds were low.)

212b. Research Reveals Laws of Friction in Lubricated Bearings.
Automotive Ind., 49:735 (1923).

Heldt reviews the work of previous researches. Tower[780] measured the distribution of pressure over the bearing surface. The greatest pressure was nearly twice the average, this being not at the center but displaced in the direction of motion. Pressure was zero at the ends. Tower found that the bearing acted as a pump. (His conclusions apply only to bearings in which the direction of the load is constant. This is not the case in auto engine bearings where the line of closest approach rotates with the shaft.) Heldt shows by the simple composition of forces why the maximum pressure is displaced from

the center. Heldt states that wear probably takes place only on starting, when the shaft and bearing are in contact.

In the case of dry friction the work of Morin [853-857] and others has shown that the coefficient of friction is independent of load and speed within certain limits. The researches of Thurston,[788] Tower,[789] and Lasche [798] show that in well lubricated bearings at constant speed the friction at first increases with specific load and then becomes practically constant, *i.e.*, the coefficient is inversely proportional to the load. The speed and the load of maximum friction increase with the temperature. Lasche finds that the coefficient increases with the speed:

$$v - \mu p(t - 32) = \text{constant} = 51$$

$p =$ load in pounds per sq. in., $t =$ degrees Fahrenheit. The range of p is from 14 to 200, t from 86 to 212, v from 3 to 65 ft. per sec.

Lubricated friction may be less than one per cent of dry friction.

Friction depends upon other things than viscosity. For instance the addition of a small amount of a fatty acid such as oleic acid will greatly reduce the friction coefficient without materially affecting the viscosity. The concept of the coefficient of friction is of doubtful value, as it is not a constant. Lasche found that the material of the journal and the bearing were of slight influence on friction, being a little lower for bronze than white metals. The choice of a bearing metal depends on other considerations. Bronze is more liable to seizure than babbitt when overheated. White metals are an advantage in many lines, for instance electrical machinery, where the hum will change tone as the bearing softens due to heating.

Bearings subjected to periodic loads will sustain greater maximum loads. For instance Tower found that with steady loads and operating in an oil bath a locomotive crank pin bearing would take a maximum load of only 400 pounds per sq. in., but in service its maximum load was 1400 pounds per sq. in. with drip feed, and 2500 pounds per sq. in. with more efficient feed. In the case of periodic loads the oil does not have time to be squeezed out from between the surfaces. The maximum load on auto piston pin bearings is about 2500 pounds per sq. in. Tower found that on reversing the motion that friction increased at first but gradually came down to its normal value. One explanation is that the fibers of the metal are turned in the direction of the motion. Reynolds, however, pointed out that the line of closest approach was not in the line of application of the load, so that if the motion is reversed, the journal must find a new seat for itself.

In practically all auto engines, oil enters through the bearing (stationary part). If oil instead entered through the journal (moving part) it could be made to enter more nearly at the line of maximum pressure at all times, which would insure more uniform lubrication. This calls for further experiment.

212c. Opinions Vary Regarding Usefulness of Oil Grooves. *Automotive Ind.*, 49:800 (1923).

Lasche[793] refers only to the grooving of bearings with ring oiling. The bearing must be recessed at the place where the ring derives most of the oil and helical grooves must be cut from here almost to the end of the bearing. Helices in the other direction should carry the oil back. The edges of the grooves must be beveled.

Morcam advocates circumferential grooving (for high speed steam engines), the two halves of the groove being staggered to avoid wearing a ridge on the journal. For extra large bearings an additional groove should be cut at the bottom of the bearing. The theoretical objections to a circumferential groove are easily proven. Tower showed that the pressure was a maximum halfway between the ends, therefore if a groove is placed here the pressure is reduced nearly to zero, and the load carrying capacity is naturally reduced.

According to Reynolds' theory of lubrication, the best results should be obtained with grooveless bearings. With other than pressure feed the pressure is nil at the points of entry and exit of the oil. Grooves cause a break in the oil film. Both of these factors reduce the load capacity.

Heldt cites the work of Kucharski,[877] who attacks Reynolds' assumption of constant oil temperature. Kucharski's conclusions follow. (1) The temperature rise in the oil film is less the smaller the ratio of length of bearing surface in the direction of motion to the longitudinal width. A division of the width, *i.e.*, by circumferential grooves, is inadvisable. (2) With the view of forming an oil film of maximum thickness, the length of uninterrupted bearing surface in direction of motion should be made less the higher the specific load and the lower the oil temperature. Best results should be obtained with a bearing of approximately square plan form. (3) The maximum thickness of oil film is not sharply defined as a function of the length-width ratio, thus allowing sufficient latitude to take care of other factors.

Another theory in regard to oil grooves is that they are required

merely to catch the worn-off particles of metal, and therefore should be most effective at the bottom. However, it is best to eliminate these by straining them out so that they settle at the bottom of the oil well.

Stanton [835] finds liberal grooving desirable for oscillatory motion (boundary lubrication). The author does not consider this a proof of the general advisability of grooving. For comparison the friction on an ungrooved bearing of the same area should have been found.

212d. Lubricating Value of Oils Is Affected by Other Properties Than Viscosity. *Automotive Ind.*, 49:842 (1923).

For the same general case of lubricant and within certain limits of loading, friction is directly proportional to the viscosity of the oil used, but not otherwise. For instance, tests on worm gears at the National Physical Laboratory (Teddington, England) showed at 104° F. the same friction loss for castor and neatsfoot oils although their viscosities are as 6 to 1. There is no good definition of oiliness. Herschel defines it as that property which causes difference in friction of oils of the same viscosity under similar conditions. Oiliness is of importance only when the oil film is incomplete. Complete lubrication obtains under 99 per cent of the operating conditions of auto engines. Vegetable oils have greater oiliness than mineral oils. Fatty oils mixed with mineral oils give the latter greater load sustaining power. Wells and Southcombe [836] claim that this is due to the content of fatty acids and glycerides.

The suggestion has been made that oiliness was a matter of lower surface tension. Wells and Southcombe found that this was the case for oil against water. Lewis found that by adding only 2 per cent oleic acid to a mineral oil the surface tension was reduced from 100 to 80. Oils with lower surface tension spread more rapidly over the surface and maintain a film more easily. A fluid is capable of acting as a lubricant only if it will wet the surface. (Great adhesion between the metal molecules and those of the lubricant is necessary.) The lubricating value of mineral oils depends on their content of unsaturated hydrocarbons, which naturally have residual affinity. Some believe that they enter into combination with the molecules of the metal surface and thus cause great resistance to the break up of the oil film.

Another approach to the subject is through the colloids. Ostwald finds that colloids do not maintain a uniform distribution where they are in contact with a surface. Usually the concentration of the colloid is greater at the surface (adsorption).

The above considerations shed some light on why a bearing metal has some effect on the friction. The character of the metal has influence on the maximum applied load in practically every case. Archbutt found that with the same load and speed and oil that a white metal would carry twice the load of a bronze bearing without increase in friction.

Objection has been raised to fatty acids in that they might corrode the journals. Southcombe states that this is not the case, although all compounded oils contain fatty acids.

Claims for fatty acids are borne out by Archbutt using a Thurston machine. Stanton, with his oscillating shaft, found that the addition of oleic acid to the oil reduced the friction.

213. Some Bearing Investigations. E. G. Gilson, *Gen. Elec. Rev.,* 27:318-327 (1924).

Results of standard type bearing testing machines are very erratic. The coefficient of friction and the temperature rise is apparently a function of the room temperature. An important factor in performance of a bearing is the internal friction of the oil. An unloaded, well-oiled bearing showed flow of the bearing metal when run at 14,000 revolutions per min. (3700 feet per min.). A new machine has been devised in which the bearing surfaces are held apart positively and an oil film constantly maintained. From tests on this machine of eight oils and ten bearing metals the following conclusions were drawn: (1) The heat of bearing is mostly generated by the internal friction of the oil film. The effect of the bearing metals, however, is largely due to their effect on the internal friction of the oil film. (2) It appears that breaking down or sludging of the oil is necessary to lubrication, the final product, however, being harmful. (3) Prevention of sludging by excluding oxygen, raises the internal friction. (In some oils break-down occurs even if oxygen is absent.) It appears as if lubrication is the act of oxidizing the oil. The decomposition product (sludge) is often of an abrasive nature. (4) The bearing should be designed to remove heat in the most efficient manner. The temperature rises very rapidly as the thickness of the film is diminished.

From a study of oil distribution with glass bushings (inside-ground) it was found that clearance was a vital factor. If difference in clearance at the two ends amounted to 0.001 in. no oil would flow to the end with the smaller clearance. Better distribution was obtained by grooving the shaft than by grooving the bearing.

214. Introduction to Lubrication Symposium Papers. (Presented at the joint meeting of the Divisions of Industrial and Engineering Chemistry and Petroleum Chemistry at the 71st Meeting of the American Chemical Society, Tulsa, Okla., April 5 to 9, 1926.) R. E. Wilson, Chairman, *Ind. Eng. Chem.*, 18:452-453 (1926).

The author gives a brief account of the present status of lubrication research. He pictures the conditions prevailing in a bearing as dependent on a struggle, on one side of which are the rotation of the journal and viscosity of the lubricant trying to drag a film of oil between the bearing surfaces, and on the other side is the load on the journal tending to squeeze the lubricant from between the surfaces. Other important variables to be considered are smoothness of bearing surface, clearance, diameter and length of bearing, method of oiling and oiliness. All of these nine variables determine the amount of friction and danger of abrasion.

Hersey [802] was the first to point out that the coefficient of friction, a dimensionless quantity, could not be a function of these nine independent variables, but only a function of dimensionless combinations of these. Thus it is possible to group the three principal controlling variables $\eta =$ viscosity, $n =$ angular speed, and $p =$ bearing pressure in the form $\frac{\eta n}{p}$. This means that the effect of doubling the speed, doubling the viscosity or halving the load must be the same. Also the coefficient of friction must be a function of the ratios of clearance to diameter or length to diameter, and not of these three variables separately. As these ratios are approximately the same for most bearings, all should give rather similar relations between coefficient of friction and $\frac{\eta n}{p}$.

These principles were first employed by Wilson and Barnard [805] to correlate a great mass of data from the literature and to give a clear idea of the nature of the function. A plot is given showing some of the data of Stribeck [792] plotted by them, the coefficient of friction being ordinates and the parameter $\frac{\eta n}{p}$ abscissæ. This paper and some of the present symposium show that while oiliness of the lubricant has no effect in the régime of fluid film lubrication, it does tend to lower slightly the critical point of film rupture and decrease the friction and abrasion in the régime of partial lubri-

cation. Barnard's paper in the present symposium shows that the oil circulation through a bearing is also a function of $\dfrac{\eta n}{p}$. Wilson mentions that work is being done at the Bureau of Standards along these lines. In particular they have obtained extremely low critical points in a large bearing with very smooth surfaces, and have been studying the effect of dirt in the oil on the friction and on the critical point with very interesting results.

Probably the work most needed now is, a detailed study of the effect of smoothness and structure of practical bearing surfaces on the critical point, because it can undoubtedly be lowered greatly below that generally found today. This would permit the use of smaller bearings and lighter oils, giving much less friction.

215. Some Little Understood Factors Affecting Lubrication. E. G. Gilson, *Ind. Eng. Chem.*, 18:467-470 (1926).

Several years ago the author obtained variations in value of friction and temperature rise of bearings by varying the room temperature only. As the ultimate temperature of the oil, and therefore the viscosity, was the same whatever the room temperature, there must have been some other factor at work.

To determine what happens to lubricating oil, a special machine was built. This consists of a steel bowl containing the oil, which rotates at high speed about a replaceable ring which may be made of any metal. The oil is thrown to the vertical wall of the bowl by centrifugal force and circulates rapidly through the space between bowl and ring.

Curves of temperature *vs.* time and friction *vs.* time are given from tests on rings of copper and of bronze, those for the bronze being considerably higher. As the same oil was used in each run and the viscosity must be lower at the higher temperature prevailing when the bronze ring is used, lower friction would be expected instead of higher. As the oil film is 0.013 inch thick it would seem that some other factor besides viscosity must be responsible.

An attempt to explain the difference between the curves by some change in the oil due to the different metals used must take into account the fact that they start off with a difference and maintain it throughout.

The atmosphere in which the machine was run had a great effect on the results obtained. In hydrogen, the friction and temperature are much higher for all mineral oils tried with one exception where

the friction was slightly lower, but the temperature much higher. If, during the test, the hydrogen is replaced by air the friction falls immediately. Castor and sperm oils give lower temperatures and friction in hydrogen than in air.

In general the oils do not sludge or blacken in hydrogen, whereas they do in air. This seems to indicate that minimum friction is dependent on a reaction within the oil that is dependent on oxygen.

A small bearing was mounted so that tests could be made on it while running in any atmosphere. The friction in a vacuum was much higher than in air. Oxygen gave lower friction than air; if the oxygen was exhausted the friction increased but not to the original value for a vacuum. The bearing was run continuously in a vacuum and readings taken at 8-hour intervals. The friction became progressively higher, and had not reached a maximum at end of the test. If the bearing was then run in air for 8 hours the friction dropped almost to its original value in oxygen.

Moisture was also found to have an effect, the friction being much less in moist than in dry hydrogen.

Conclusions. The experiments indicate that for efficient lubrication some kind of reaction is necessary which is dependent upon the presence of moisture and of oxygen. The fact seems to be well established that the surrounding atmosphere has a very decided effect upon the friction obtained. The differences in friction cannot be accounted for by differences in viscosity of the oil. All of the friction curves tend to come together in the region around 100° C., but it is not yet known whether or not this has any significance.*

215a. The Lubrication of Surfaces under High Loads and Temperatures. T. E. Stanton, *Engineering*, 124:312-313 (1927).

The author emphasizes the difference in the values obtained for the coefficient of friction in thick film lubrication and in "boundary lubrication". In the former the coefficient of friction may be as low as 0.001, while in the latter it may be a hundred times as great. Reference is made to the statement of Lanchester at the Physical Society conference on lubrication in 1919. Lanchester said: "In about 1890 I found myself in charge of a test bench at a works manufacturing gas engines, and it was my invariable practice if a bearing ran hot when first on test, to substitute castor oil for the mineral oil usually em-

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* Possibly the phenomena can be partly accounted for by different rates of convection of heat from the bearing in the different atmospheres.—ED.

ployed, when all difficulty at once vanished". Stanton interprets this to mean that the surfaces were in actual contact due to faulty machining, and that the lower coefficient of friction given by castor oil at the temperature already attained enabled the journal to run until sufficient wear had taken place to establish a film. After the film was once established it was possible to revert to the mineral oil. Fluid film lubrication, in which Reynolds' conditions obtain does not exist in a great many cases. These cases, in which boundary lubrication exists, are of great importance to the engineer, but the condition is one to be avoided. There is considerable evidence to show that seizure of a cylindrical bearing, as the load is progressively increased, coincides with the transition from fluid-film to boundary lubrication.

The author gives a theoretical curve, plotted in polar coordinates, of eccentricity of the journal against the angle between the line of centers and the horizontal. The low eccentricity (small load) portion of this curve is based on the work of Osborne Reynolds and the high eccentricity (high load) portion on the work of Sommerfeld. At zero load, the point of nearest approach of the journal and the bearing is vertically over the axis of the journal. As the eccentricity increases, though still remaining small, the point of nearest approach moves over to the "off" side of the bearing, and as the eccentricity is increased to large values it moves back again until the angle of the line of centers to the horizontal is about 45°. Increasing the load still further moves the point of nearest approach over to the "off" side again, where contact theoretically takes place.

Measurements of the relative displacements of journal and bearing were made by Thomas using his electrical inductance method described on p. 24 of the July 1, 1927, number of *Engineering* [also *Engineer*, 135:138 (1923)]. A journal 7.6 in. in diameter by 8.5 in. long was run in a complete oil bath at a constant speed of 134 revolutions per minute (265 surface ft./min.). Loads up to 9000 lbs. were used, giving values of eccentricity up to 0.77. The viscosity of the oil used was 0.2 poise. Up to an eccentricity of 0.5, fairly good agreement was obtained between theory and practice but beyond this point, the point of nearest approach moved toward the crown of the bearing instead of in the opposite direction, as indicated by the theory.

An explanation of this was sought for. The theory indicates that negative pressure should exist over a considerable arc on the "off" side of the bearing. In these experiments it is probable that negative pressure could not be obtained, owing to the fact that air was drawn

in at the ends of the bearing, with the result that the oil film retreated toward the crown of the bearing. This was confirmed by experimental measurement of pressures at different points of the bearing, and affords an explanation of the observed movement of the point of nearest approach. This probably also explains the low values of seizing pressure in Tower's experiments, even with the lower surface of the journal immersed in an oil bath.

Other tests were made in which, instead of using bath lubrication, oil was supplied to the unloaded side of the bearing by an oil pump. At low loads, artificial heating was necessary to obtain the desired temperatures. The bearing used in these tests was a complete bush without oil grooves.

As the temperature rises, the coefficient of friction first drops to a minimum, beyond which it increases gradually with further rise of temperature, until at a certain critical temperature, the seizing temperature, a very sudden increase in the coefficient of friction occurs, and the surfaces will seize unless the machine is stopped.

Curves are given of coefficient of friction against temperature for loads of 500 and 2500 lbs. per sq. in. on a journal 2.0 in. diameter by 2.25 in. long, rotating at 1300 revolutions per minute. Two mineral oils and castor oil were used in different tests. The results are as follows:

| | Coefficient of Friction | | Seizing |
Lubricant	Static Deeley Machine	2500 Lbs. per Sq. In., Minimum Coefficient	Temperature °C.
No. 1 Mineral................	0.125	0.0018	94.5
No. 2 Mineral................	0.126	0.001	224
Castor Oil	0.08	0.0012	138

The author's conclusions are:

(1) "That the known merit of castor oil in preventing the failure of bearings running hot is not due to inability to seize. This happens in fact at a relatively low temperature, but as previously mentioned, it is due to the low coefficient of friction under boundary lubrication conditions.

(2) "That it is possible to obtain a straight mineral oil which maintains itself in the film condition up to temperatures far in excess of the limiting temperature for castor oil.

(3) "That mineral oils of the same degree of acidity and unsaturation, and for which the values of the viscosity and density are approximately the same, may vary greatly in their capacity to stand up at high temperatures under conditions of film lubrication."

Oils, then, which are best under boundary lubrication conditions, are not necessarily best under film lubrication conditions and *vice versa*.

In the discussion, Sir K. Threlfall asked if minute chemical analyses had been made of the oils used. In reply, Stanton stated that only acidity and saponification tests had been made. Sir K. Threlfall then remarked that some unrecognized constituent might account for the behavior of the oil and bring it into line with Sir Wm. Hardy's views.

216. The Microstructure and Frictional Characteristics of Bearing Metals. M. Price, *Trans. Am. Soc. Mech. Eng.*, 26:669-712 (1905); *Am. Machinist*, 29(2):505-511, 535-541 (1906).

The objects of the present research are: (1) to find the law of variation of friction with speed, (2) to test Charpy's theory of the function of hard grains embedded in a plastic matrix, (3) to test Goodman's theory that a third metal added to an alloy increased the friction according to its atomic volume.

Morin's results are pretty convincing but are for sliding friction on a rectilinear track while most other investigators have used rotative devices. Morin's conclusions are: (1) friction is proportional to the pressure, *i.e.*, the coefficient is constant, (2) for the same pressure the coefficient is independent of the area of contact, (3) the coefficient is independent of the speed, except that static is greater than moving friction.

Goodman found: (1) friction is proportional to the area in contact if the pressure is the same, (2) at low speeds the coefficient is abnormally high. The minimum coefficient is for a speed between 10 and 100 ft./min. At speeds greater than 100 ft./min. the coefficient is proportional to the square root of the speed.

The author shows that Morin's results may be explained by poor contact of the surfaces used. The author constructed a friction testing machine consisting of a shaft rotating in a half bearing. The shaft was first set in rotation free of the bearing, then dropped into it and the power shut off. The revolutions per min. of the shaft was taken at given intervals. The results obtained with poor fitting bearings confirm Morin's laws, and those with well fitting ones confirm the findings of more recent workers.

Examination of a white metal bearing taken from shop service showed abrasion, *i.e.*, metallic contact, only over about 2 per cent of

its area and of this a large part was due to dust and grit, being mostly at the ends. A smaller bearing showed a much greater area worn, but was used with an untrue journal. The half bearing was next constructed of a series of alloys.

The bearing surfaces in the author's apparatus were very small, $1/4$ in. diameter by 0.04 in. long, being step bearings on either side of the flywheel. The bearings were oiled with mineral oil after each one or two runs.

The performance curves were reduced to the same time scale on the basis of a few representative ones for each alloy. These graphs (speed *vs.* time) are shown. The author ascribes certain peculiarities of these curves to the addition of different constituents to the alloy. Goodman's results were not confirmed, but this was not to be expected altogether as Goodman used dry bearings.

Photomicrographs of some of the alloys are shown. The hardness was studied with a sclerometer or by noticing the behavior during polishing.

The author could find no general law describing the performance of all the alloys. The softer metals showed greater change in resistance as the speed decreased. The variation in the shape of the curves is apparently not due to abrasion; the peculiarities, however, seem to be correlated with the chemical composition.

The author's results seem to contradict Charpy's theory that the hard grains contribute the antifrictional properties. The author found that pure metals ran longer than alloys.

217. Surface Action and Fluid Film Lubrication. A. E. Becker, *Ind. Eng. Chem.*, 18:471-477 (1926). 17 Figures.

From his mathematical analysis Reynolds[806] concluded "that with a particular journal and brass the mean thickness of the film of oil would be sensibly constant, and hence if the viscosity was constant the resistance would increase directly as the speed". The experiments of Tower,[780] however, showed that the resistance increased at a much slower rate. According to Reynolds, then, "either the boundary actions became sensible or that there must have been a rise in the temperature of the oil which had escaped the thermometer used to measure the temperature of the journal". Reynolds chose the latter alternative explanation.

The present paper aims to show that Reynolds' first alternative

is of prime importance in the formation and maintenance of fluid film lubrication.

No satisfactory means have as yet been devised for measuring the adhesive forces between lubricants and metals. Probably these are entirely different in a bearing than where the same surfaces are exposed to the atmosphere, because the rubbing action in oil will finally remove all oxide or other contaminating surface films.

The things of interest are the magnitude of the oil film in a bearing and the amount of friction. The author has devised a method for measuring the former. This consists in measuring the thickness of the film by an electrical method. A small thrust bearing is used, the two surfaces of which form the conducting surfaces of a condenser, the oil in between being the dielectric. The capacity is determined, and hence the thickness, by the use of an alternating current bridge.

The film-thickness was measured under varying conditions of speed, load, and oil viscosity, and an empirical equation derived as follows:

$$t = K\left(1 - \frac{\log \eta}{C}\right)\left(1 - \frac{\log n}{B}\right)\left(1 - \frac{\log P}{A}\right)$$

where:

t = film thickness.
η = oil viscosity.
n = angular speed.
P = load.

K, A, B, and C are constants depending on the surface action forces.

The constants A, B, and K are changed by changes in either oil or bearing surfaces, the constant C is affected only by changes in the bearing surfaces.

The experiments demonstrate that oil film thickness in a given bearing depends on surface action as well as on viscosity. It is highly probable that the surface action effect is partly due to the surface structures of the two bearing elements and partly due to adhesive forces between the lubricant and the bearing surfaces.

It does not follow that two bearings in which the same film thickness is formed will operate equally well. The author found that cast iron surfaces operated smoothly and without damage to the surfaces for much thinner films than magnesium surfaces, partly perhaps because the latter became damaged more easily during starting and stopping.

218. **The Rôle of Oiliness in Industrial Lubrication.** W. C. Wil-
harm, *Ind. Eng. Chem.*, 18:463-467 (1926).

Electrical machinery is being built larger and heavier to satisfy
the demands of super-power. The conditions are often such that bear-
ings cannot be increased in size in the same ratio as the rest of the
machine. Bearings are now sometimes subjected to double the load
per unit area that was considered safe several years ago, consequently
more is demanded of the lubricant than formerly.

Of all the properties generally measured in lubricant tests, viscosity
is the only one that is any measure of lubricating value. Fluids, how-
ever, of the same viscosity have different lubricating values, so that
some additional test must be devised.

Mechanism of Lubrication. A well designed, well machined bear-
ing, running at a fair rate of speed runs for the most of its life on a
film of oil. Under these conditions friction depends on the viscosity,
and a low-viscosity lubricant would be desired except for the fact
that other conditions sometimes occur. Sometimes metal-to-metal con-
tact occurs and viscosity is replaced in importance by a property of
the lubricant known as oiliness. Wilson and Barnard [895] define oili-
ness as that property of lubricants by virtue of which one fluid gives
lower coefficients of friction than another fluid of the same viscosity,
generally at low speed or high loads.

Importance of Oiliness. On starting and stopping a machine, the
speed is insufficient to maintain the oil film in the bearings. To insure
presence of an oil film a larger part of the time, more viscous oils
are used, but this increases the friction and power loss. It is not so
important to maintain the oil film if there is a property of the lubricant
which reduces friction and prevents abrasion under these conditions.

The bearing pressures in some electrical machinery are so high
that it is doubtful if fluid films are ever formed. In such cases, oiliness
is all-important. The lubrication in gears, pistons, crossheads is of the
same type.

Nature of Oiliness. Fatty oils and acids invariably give lower
values of static friction than mineral oils, under conditions of rup-
tured film lubrication. Oiliness and its mechanism is still a question
of discussion. Wilson and Barnard ascribe oiliness to a constituent
of the lubricant which forms a tenacious adsorbed film of colloidal
dimensions on metallic surfaces and thus prevents metal-to-metal
contact. Hardy and his co-workers in their researches on ruptured-film
(boundary) lubrication state that this type of friction follows

Amonton's law of sliding friction, *i.e.*, friction is proportional to the weight of the slider and independent of the area of contact. They picture a film of lubricant several molecules thick built up owing to the orientation of the molecules as described by Langmuir,[923] thus preventing the attractive force of the surface from exerting its full influence. They found much evidence that friction is a function of the chemical constitution of the lubricant.

Southcombe and Wells [830] found that compounds that lowered the interfacial tension between water and oil gave exceptionally good lubricating values. It cannot be concluded from their experiments, however, that any substance that lowers this tension is a good lubricant. Wilson and Barnard have made similar measurement on various substances and mercury, and found that materials of low surface tension are not always good lubricants. Evidently the nature and structure of the film are also of importance, as many compounds of low surface tension are deficient in oiliness.

Measurement of Oiliness. It would seem natural that this property should be measured on a specially designed bearing testing machine, but as measurements must be taken when the fluid film is ruptured, and the surface becomes damaged under these conditions, reproducible values cannot be obtained. The surface cannot be reground without changing test conditions.

The simplest and most effective method seems to be the measurement of static friction under relatively high pressure. The author used a modification of the method used by Hardy and Doubleday [838] and by Wilson and Barnard.[895]

The author used an apparatus consisting of a slider moving on a specially prepared inclined plane. The bearing surface of the slider consisted either of three steel pegs 0.10 inch in diameter, ground and polished as flat as possible, or three steel balls, one inch in diameter. The instant of slip was detected by the making of an electric contact. To prepare the surface in the first place and again when changing lubricants, it was ground and polished with lubricant-free material.

A series of tests was made with the slider bearing on three pegs. The lubricant was a straight steam-distilled paraffin-base oil made from a Franklin, Pa., crude. It was dewaxed by refrigeration and centrifuging and not by partial cracking. Its specific gravity was 0.879 at 15° C. and its Saybolt viscosity was 693 sec. at 100° F. and 354 sec. at 130° F.

The coefficient of friction increases from 0.16 at a 200 gram load

to 0.176 at 500 grams and remains fairly constant at this value up to the highest load, 3800 grams. The coefficient was the same whether the excess oil was left on or removed by wiping with a clean cotton cloth so that no visible film remained.

When the film of oil was washed from the surfaces with soap and water and dried with ethyl alcohol and surgical cotton the coefficient dropped to 0.1. This is probably due to the fact that the surfaces adsorbed a film of soap and the coefficients obtained are those for the soap.

Further tests were made with other lubricants. The crude from which the above oil was refined gave a coefficient of 0.188 in spite of the fact that its viscosity was less than one-fifth that of the refined oil. If oleic acid was rubbed into the crude oil film, the coefficient dropped to about 0.12.

The brass plate was again reground and some experiments made, using the slider resting on the three balls. The values obtained checked those obtained with the flat surfaces and heavy loads. A large number of consecutive tests were made, using a new part of the brass surface each time. After 30 tests the coefficient dropped from 0.19 to 0.16 after 40 tests but rose again slowly after this.

Theory. Microscopical examination showed that the surface of the weaker metal where motion occurred was cut, and that the harder metal had a spot of softer metal built up on the area of contact. The brass plate was cut by the steel balls in the direction of the motions. The same effect was noted by Martin [890] in making oil tests with brass and steel surfaces. Why should this happen if the surfaces are separated by adsorbed films of more than molecular thickness?

This cutting action seems to be in agreement with the theory of Bingham [892] on the mechanism of cutting fluids. His theory is that the cutting tool acts as a wedge, forcing a chip from the metal and the lubricant acts to lubricate the sides of the wedge. Friction may in part be due to this cutting action. No actual surfaces are perfectly smooth but have numerous small projections which act as cutting tools, and the lubricant functions in the same manner as in cutting with machine tools.

Coulomb in 1785 proposed the theory that friction was due to interlocking projections. This was contested by Rayleigh [915] and by Hardy, [894] who attributed friction to the mutual attraction of the metallic surfaces. This hardly explains the cutting action; it is not conceivable that the attractive force of two surfaces acting through

an intermediate layer of lubricant would be great enough to overcome the cohesion of the metal molecules.

It is possible that the initial increase in friction with increasing pressure may be due to the fact that more of the projections interlock and the constant value assumed above a certain pressure would seem to indicate that the oil film has thinned to the limit and that higher pressure within the limits of the test can cause no further interlocking of projections. The reduction in friction after numerous tests may be due to the building up of the brass spots on the steel contact areas smoothing over the irregularities, a phenomenon similar to the running in of bearings.

If the author's assumption regarding the interlocking projections is correct the following conclusions may be drawn:

"(1) The secret of good oiliness would be to have a tenaciously adsorbed film of such thickness that the projecting asperities would not interlock.

"(2) The friction would be a function of the attractive forces of the metals, the tensile strength of the metals, and the internal friction of the lubricant. This may partly explain why softer metals such as babbitts give lower resistance than harder metals".

219. The Rôle of Graphite in Lubrication. F. L. Koethen, *Ind. Eng. Chem.*, 18:497-499 (1926). 6 Figures.

Where the fluid film in a bearing is ruptured and actual rubbing takes place, lubrication is accomplished by adsorbed substances which prevent clean metallic contact, the main cause of friction. The problem of securing lubrication under these conditions is a chemical one, the viscosity of the oil having little effect. This broken film stage affects operation seriously because of the damage done when the film does break, also because many bearings in service have one or more streaks in which the film is broken. These streaks carry most of the load and produce most of the friction.

The author made some tests on the effect of graphite on lubrication, using a Riehle friction testing machine, in which a 3-inch steel shaft rotated between cast iron bearing blocks. After running for 70 hours with a 300-viscosity motor oil conditions became constant at 19 pounds torque and 100 pounds per sq. in. pressure, the speed being 196 feet per min. Repeated trials at higher loads resulted in greatly increased friction and scoring of the surfaces. Graphite was introduced into some of the same oil and the bearing run long enough

to form a graphite surface. Colloidal graphite (Oildag) was used: first 2 hrs. with 13 per cent graphite, then 6 hrs. with 6.25 per cent graphite and finally 8 hrs. with 0.25 per cent graphite. Conditions were then constant with the torque at 16 pounds under a bearing pressure of 100 pounds per sq. in. The pressure could be raised to 180 pounds per sq. in. before the torque of 19 pounds was exceeded and the film commenced to break down. That is, the oil still sets the lower limit for friction, although the addition of graphite resulted in a great increase in permissible bearing pressure.

Static friction tests were made with a slider resting on three steel balls which was drawn over a flat horizontal metal plate by means of a thread passing over a pulley, a weight pan hanging on the other end of the thread. The plate was made either of shafting steel or babbitt. Results of different oils and of effect of powdering the oiled surface with dry graphite are given. The results confirm the fact that the addition of fatty acids to a mineral oil improves the lubrication by this oil. They prove that pure graphite definitely reduces the boundary friction.

The graphite undoubtedly fills up some of the minute scratches and roughnesses of the metal, thus producing a smoother surface, but owing to the soft friable nature of pure graphite, no great width or depth of scratch can be filled in this way. There is also a tendency for some of the graphite to be rubbed and pounded into the metal particularly at the high spots. It has not yet been proved whether solid graphite is actually adsorbed to solid metal.

The fact that oil will displace water from graphite surfaces by preferential adsorption is of importance in the case of bearing surfaces subjected to water, such as steel rolling mill necks. These necks often rust within 10 minutes after the mill is shut down. If they are graphited, however, this preferential adsorption of graphite for oil rather than for water is very effective in maintaining an oily or greasy surface.

220. **Lubrication.** W. R. Ormandy, *Mech. World*, 8:326-327, 360-361, 393-394 (1927).

The problem of lubrication is essentially that of liquid and solid interfaces, surfaces which may be the seat of intense forces.

It has been argued that the work required to bring all the molecules of a bulk of liquid to the surface must be one-half of the latent heat. This is approximately the case with non-polar molecules. If the

molecules have chemically active groups on their ends, as do the
acids and alcohols, the work required to tear a molecule away from
the surface would seem to be over one-half of the whole latent heat.
The apparently justifiable assumption has been made in the above,
that the time a molecule spends in the surface layer is long compared
with its natural period. These conclusions are borne out by the work
of Harkins and Robert, comparing the surface energies and latent
heats of a series of compounds at corresponding temperatures. Thus
the ratio of surface energy to latent heat is 0.452 for the symmetrical
compound carbon tetrachloride, while it is only 0.186 for the polar
compound, ethyl alcohol. The properties of surface layers are largely
affected by the shape of the molecules and the presence of polar groups.

Unimolecular Character of Surface Films. Langmuir, experi-
menting on films of solids on water, found that they were liquid below
a certain thickness. He measured the surface tension of films of known
thickness. From the results of these tests he computed the cross-
section of the molecules and made an estimate of their length. The
molecules of the fatty acids have practically the same cross-section,
but they vary greatly in length. The glycerides occupy about three
times the area of the acids from which they are derived. As the dis-
tance between the carbon atoms of these compounds is less than
between those of diamond (1.5 Å.), it has been suggested that in long-
chain compounds the carbon atoms are arranged either in spiral or
zigzag formation. If solids possess surface forces similar to those of
liquids it might be expected that polar compounds would take up
oriented positions thereon. As the length of the chain increases, the
attraction between adjacent chains increases, and the space occupied
by the polar head lessens. Values are given of the energy necessary
to divide a liquid or to separate one liquid from another.

On the basis of the modern theory of crystal structure it would be
expected that the atoms on the edge of a crystal would exert greater
forces than those in the center of a crystal face, or further that micro-
crystalline or amorphous material would exert greater external action
than material composed of large crystals. This is actually the case.
That solids do have surface energy is shown by the fact that freshly
split pieces of mica adhere perfectly, or that clean platinum faces
weld together far below the melting point of platinum. The energy of
crystal faces varies with the packing of the atoms in the face and
with the distance from the next face. In crystals of common salt it
may vary in the ratio of 1 to 4. Added substances may greatly affect

the surface energy of a solid. Metallic surfaces prepared for catalytic purposes are not equally active all over. The external field of a metal extends, though greatly weakened, out for several molecule diameters from the surface.

It is a question of interest if polar bodies are oriented on solid surfaces as they undoubtedly are on liquid surfaces. The X-ray investigation of Shearer shows that this is the case with fatty acids on mica. Hardy showed that while saturated hydrocarbons were adsorbed by most solid surfaces, they are very easily displaced by others having polar groups. In the case of the reaction between hydrogen and ethylene at the surface of a copper catalyst, it is believed that the small part of the surface which brings about the actual reaction is amorphous, that is, both gases are adsorbed by the edges and corners of the microcrystals.

Liquids which have a low surface tension, like oils, are more likely to wet solids than those which have a high surface tension. Wetting may be prevented by adsorbed gases, thus mercury will wet glass only in a very high vacuum. Some solids adsorb unsaturated bodies more readily than saturated ones.

Work of Hardy and Colleagues. If two optically true surfaces are brought together with a thin layer of a non-polar substance between them, the friction between the two assumes its minimum value at once; if, however, the substance between the surfaces is a polar one, there is a time lag before the minimum value is attained. It has been suggested that this time is necessary for the orientation of the polar bodies. A lag, but of shorter duration, is exhibited by a polar substance mixed with a non-polar one. Hardy and his co-workers observed the time necessary to squeeze out an excess of oil from between two plane plates. The oil behaves as though it possessed a much higher viscosity than the same oil in bulk, even when the layer of it is many molecules thick.

The frictional resistance in a steady state is independent of the temperature, but the time required to reach equilibrium (duration of latent period) is reduced by mechanical agitation and by raising the temperature.

If more than 0.7 per cent of a polar body is mixed with a non-polar body, the coefficient of friction is of the same order of magnitude as that of the polar body alone. This is of great practical importance and is referred to in the work of Southcombe. Hardy observed that the friction varied inversely as the pressure up to a certain pressure

and from there on was independent of the pressure. His explanation is that the oil film is squeezed thinner and thinner, finally becoming of molecular thickness. In the first stage the friction adjusts itself to the load by variations in the film-thickness, but in the second stage, friction arises from elastic forces between the atoms. The materials of solid surfaces have an appreciable influence on the friction even when the layer of oil is several molecules thick.

Two clean, plane metallic surfaces will seize if an attempt is made to move them tangentially over each other. There is still great resistance to motion if a lubricant with a low vapor pressure, such as oleic acid, is brought into contact with the edges of the plates. The mere presence, however, of the vapor of a polar liquid having a high vapor pressure will allow the two plates to be slid over each other with little effort.

The problem of lubrication is concerned with the question as to whether "oiliness" is a real property of bodies. No means have as yet been devised for its measurement. The property of adhesion is probably at the foundation of the concept of oiliness and is of enormous import when the oil film is very thin.

Experiments have generally been carried out, either with films of limiting thickness or else with complete lubrication. It is to be doubted if the condition of limiting lubrication occurs in practice except very rarely. In motor cars it may obtain on starting up after long standing, but only momentarily.

If the rate of shear of a liquid is small, the resistance to a body in motion in it is proportional to the viscosity and to the speed. The viscosity of surface layers may be much higher or much lower than the viscosity of the bulk of the liquid.

The electrical resistance of oil films, or paraffin films between disks is surprisingly low. (Greasing the terminals of storage batteries apparently introduces no additional resistance.)

Compared with mono-molecular layers, even optically true surfaces are immensely irregular. If they are accurate to one-fifth of the wavelength of sodium light, the unevenness is of the order of 1000 Å., while the length of a molecule of stearic acid, containing 18 carbon atoms in its chain is about 25 Å., that is the unevenness is of the order of 40 molecule lengths. Such surfaces may therefore be in contact at two or three points, but far from contact in most places.

There is some indication in Hardy's work that the state of polish affects the results. This is to be expected if we agree with Beilby that

the effect of polishing is to create an amorphous layer, for it is probable that surface forces are very great in amorphous material.

Viscosity is of importance in perfectly lubricated bearings. The viscosity-temperature curves of different oils differ at low temperature but approach each other more and more closely between 200° and 300° F. Generally oils of low specific gravity have flatter viscosity-temperature curves than those of lower specific gravity. This is not always the case, as much depends on the methods and degree of refining.

Resistance to Oxidation. Moore pointed out that the most frequent cause of defective lubrication in modern machinery was from oil oxidation. This results not so much in loss of oiliness, as in the formation of asphalt-like products which obstruct the oil ducts. Oxidation is greatest with over-refined oils. The presence of finely divided metal increases oxidation greatly, hence the importance of crank-case oil filtration.

The author enumerates some problems to be solved in coöperation by the physicist, chemist, engineer and oil manufacturer with view of producing better lubricating oils.

221. The Heat of Wetting of Metals by Oils and Its Relationship to Lubricating Power. Wm. Bachmann and C. Brieger, *Kolloid-Z.,* 36A:142-154 (1925).

GENERAL AND THEORETICAL PART.

The Testing of Lubricants. The authors enumerate the manifold tests applied to lubricants, the chemical tests such as determination of acidity or alkalinity, the capacity of resinification, oxidation, the content of impurities, etc., and the physical tests for color, specific gravity, thermal expansion, viscosity, etc. Other data of importance are: cold, flash, and burning temperatures, volatility at working temperatures, optical properties as index of refraction, etc.

These tests, however, still do not give a complete idea of the value of an oil as a lubricant.

Concept of Lubricating Power. Two oils very similar in physical and chemical properties may be required in very different quantities to produce minimum lubrication (just sufficient oil to lubricate). Duffing and Dallwitz-Wegener [1039] have defined lubricating power as the inverse of this quantity of oil to produce minimum lubrication. They found that lubricating power depends on the force with which the oil is adsorbed by the metal. The tenacity of the oil film would

then seem to depend on the capillary properties of the oil and metals of the bearing and journal. Dallwitz-Wegener [1040] has given a series of methods by which these may be determined. An oil has higher lubricating power the smaller its angle of contact and the lower its surface tension with respect to the metal. Methods of determining surface tension are given by Dallwitz-Wegener.[1040]

Heat of Wetting as a Measure of Capillary Forces. According to recent adsorption theories, the surface of an adsorber is the seat of a field of force, the resultant of the residual valencies of the atoms on the surface. Adsorption consists in saturating these valencies with secondary valencies of the adsorbed molecules. The heat effect occurring on adsorption is called the heat of wetting.

Heat of Wetting. The authors give a table of the heats of wetting of various powders by different liquids. No values higher than 80 cal. per gram of adsorbing substance are given (excess of liquid present). This small heat effect precludes its determination at a solid metal surface. A much larger surface must be exposed to the liquid.

Observations of Southcombe and Wells. An inspiration to the authors' research was given by the work of Southcombe and Wells [830] which led to British patent No. 165,897. These authors discovered that quite small amounts of unsaturated groups made an extraordinary increase in the lubricating power of a poor lubricant and thus reduced the minimum quantity necessary for lubrication. According to Gurwitsch [922] certain unsaturated compounds have high heats of wetting, though with quite other adsorbers.

Wells and Southcombe sought after an explanation of this increase in so-called "oiliness" or "body", which they found to be caused by the glycerides of the fatty acids. They determined the surface tension of various oils to water by Donnan's method and found that vegetable and animal oils had considerably lower surface tensions than mineral oils. They explained this as due to the presence of unsaturated compounds, especially free fatty acids in the former oils. The neutral glycerides have surface tensions of the same magnitude as those of the mineral oils. This assumption was shown to be correct by the fact that the lubricating power of neutral glycerides or mineral oils was increased by the addition of a small amount of a fatty acid. The unsaturated groups and fatty acids in a lubricant go direct to the metallic surfaces and form an adherent film thereon which offers considerable resistance to being torn away even at high velocity of the lubricant relative to the metal. According to P. V. Wells [980] this

layer, in particular with oleic acid, is of bimolecular thickness, *i.e.*, about 4×10^{-7} cm. There is no reason for doubting the existence of such a film on the metal surfaces having a different constitution from the body of the lubricant.

EXPERIMENTAL PART.

The lubricating power is determined by the "activity" of the lubricant with reference to the bearing metals, therefore by the force with which the oil or a constituent of it is selectively adsorbed by the metallic surfaces. This "physico-chemical force of attraction" finds a direct expression in the heat of wetting.

The authors state that to their knowledge the heat of wetting of metals by oils has not yet been measured.

They select three classes of lubricants:

1. Oils of evident lubricating power.
2. Poor lubricating oils.
3. Petroleum with additions of fatty acids in sense of Southcombe and Wells.

In order to lower the viscosity and accordingly impart easier miscibility the authors diluted all their oils except petroleum with benzol in the ratio of 2 parts oil to 1 part benzol.

The adsorbing medium used was finely divided copper prepared by reducing cupric hydroxide in a current of hydrogen.

Apparatus. The apparatus used is described in detail. The copper powder was placed in a glass tube through which passed a rod whose lower end terminated in a glass stopper ground to fit the lower end of the tube. The whole was immersed in oil in a Dewar flask and at a given instant the stopper was pushed out, allowing the copper powder to mix with the oil. About 20 grams of copper and 200 cc. of oil were used. Temperatures were measured with a resistance thermometer.

The Adsorber. The cupric hydroxide was reduced in a current of hydrogen at a comparatively low temperature so that its fine structure was preserved and a powder could be obtained, all samples of which had the same specific surface.

Measurements. The temperature increase was plotted against the time. The curves showed a marked change of slope due to the evolution of heat when the copper was wet by the oil. The distance between the prolongations of the first and last portions of the curve was taken as a measure of the heat of wetting. These results are given in the table below.

Benzol is seen to have a very small heat of wetting, and therefore the amount of this adsorbed by the metal will be small. Hence it can be assumed that the undiluted oil will have a heat of wetting determined from the heat effect and the actual quantity of oil in the mixture.

Relation of Heat of Wetting to Lubricating Power.

Oil	Temperature Rise/20 per Grams Cu with Benzol °C.	Temperature Rise/20 per Grams Cu without Benzol °C.	Heat of Wetting per 100 Grams Cu °C.
Castor oil	0.018	....	11.75
	.019	....	12.40
Linseed oil	.023	....	14.45
	.021	....	13.25
Machine oil distillate	.022	....	14.55
	.021	....	14.00
Refined machine oil	.010	....	6.65
	.009	....	5.95
Paraffin oil	.006	....	3.85
	.006	....	3.85
Petroleum	....	0.007	5.3
	....	.008	6.0
Benzol	....	.003	....
	....	.004	....
Petroleum with 1 per cent oleic acid	....	.029	22.0
	....	.027	20.5

These results support the conclusion of Southcombe and Wells that the fatty acids are capable of forming an extremely stable and tenacious film on the bearing surfaces and are a very favorable addition to make to other oils.

These results will throw some light on reason for the extraordinary lubricating power of colloidal graphite, a phenomenon which has never been satisfactorily explained. A higher heat of wetting of graphite by an oil is to be expected than of a bearing metal of equal surface by the same oil. Graphite has a strong attraction for oil. Acheson (German patent No. 230,586) found that oil displaced colloidal graphite from its state of dispersion in water, the water micelles around the graphite particles being replaced by oil micelles. It can now be seen why graphite acts as an economizer of oil: it allows the formation of a thin, stable, and tenacious film, such as is expected with a good lubricant, on the surface of graphitized bearings.

222. Materials in Modern Turbine Construction. A. Thum, *Z. ver. deut. Ing.*, 71:753-765 (1927). Bearings on p. 762.

While satisfactory radial bearings for turbines are quite old, the thrust bearings have been a source of trouble until quite recently.

The basis for the design of a serviceable thrust bearing was laid by Reynolds, Sommerfeld, and Michell, who showed that a viscous film of lubricant between two surfaces moving past each other and inclined at a small angle to each other was able to take up large loads in virtue of its internal friction, and to force the two surfaces apart. From this arose the single collar thrust bearing, which in contrast to the old multiple collar thrust bearing is not only much more reliable but gives lower frictional loss.

While the question of bearing friction has been rather thoroughly studied from a physical standpoint there is still much work to be done in developing more suitable materials for turbines, above all suitable turbine lubricants. Only refined mineral oils can be considered for the lubrication of turbines. It is desirable that they have an Engler viscosity of 3 to 5° at 50° C. The thrust bearings are too sensitive if lower viscosity oils are used, even if the friction is somewhat lower.

With driving turbines, a heavy oil of at least 6 Engler degrees at 50° C. must be used to lubricate the rapidly moving gears.

Present day turbine oils are satisfactory with respect to viscosity wetting power, and lubricating power, but they age rapidly. In the course of time tar, slime, acid, scum and emulsions are formed in them. In its passage through the oil cooler and the water separator the oil comes into contact with air and is partially oxidized. The oil also becomes full of air bubbles which are not conducive to perfect lubrication.

The oil may form an emulsion with water from leaks in the cooling coils or from steam leaking through the packing. The oil tends to emulsify more the longer it is in service where it is exposed to oxygen. In order to produce non-emulsifying turbine oils the refining must be carried further than at present, and a new test must be devised which will distinguish an emulsifying oil from a non-emulsifying one.

Although in normal running there is no metallic contact between shaft and bearing and the question of bearing metals might be thought entirely subsidiary, actually the choice of a bearing metal is of great importance. It must be especially resistant to abrasion on starting and stopping, when metallic contact occurs. A good bearing metal must have a melting point much different from that of the journal and will melt before the latter becomes damaged. A high-tin white metal has proved to be best for the radial bearings. Its Brinell hardness should be at least 35. Bearing metals containing much lead are not recommended where pressure oil-feed is used because the lead is oxidized

and washed out by the vigorous oil circulation. For the single collar thrust bearing, white metal is somewhat too soft and it is better to use here a hard tin bronze.

223. Some Experiments on the Oxidation of Lubricating Oils. H. Moore and J. Barrett, *J. Inst. Petroleum Tech.*, 12:582-585 (1926).

The authors consider that when dealing with practical lubricants and their application, oiliness, on which so much research work has been done, is of secondary importance to resistance to oxidation. Most machinery operates under conditions where oiliness does not come into play. They conclude that the majority of failures due to the lubricant are caused by oxidation of the oil.

Bearing failures fall into two classes: (1) The lubricant had insufficient oiliness to keep the surfaces apart. (2) There was an inadequate supply of oil due to formation of deposits in it.

The first type of failure is liable to occur in experimental or poorly aligned machinery. In failures of the second type, the oil may change so that the pumps or other feed devices will not work properly. Change is either an oxidation accompanied by a great increase in viscosity or by the deposition of solid substances. If water is present the liability of emulsions forming is greatly increased. Oxidation is of not much importance in slow drip feed, but very much so in modern continuous circuit lubrication.

The authors tested seven oils of about the same viscosity and one of higher viscosity for the effect of oxidation. Air was blown through the oil at 200° C. according to the Air Board Specifications (British). Viscosity was determined with the Redwood viscosimeter. Some of their results are given in the following table.

Effect of Oxidation on Viscosity of Oils.

Name of Oil	Specific Gravity	Viscosity 100°F.	Viscosity after Test / Viscosity before Test	
			100°F.	200°F.
Russian pale oil....................	0.909	387	2.3	1.25
California red oil...................	.928	398	6.7	3.0
California pale oil..................	.928	386	6.1	8.4
South American red oil............	.930	354	over 20 ?	8.25
Mixed base red oil.................	.910	434	2.3	1.6
Pennsylvania long residuum oil.....	.879	612	1.5	1.5
Russian cylinder oil................	.912	760	1.6	1.2
Texas red oil......................	.939	418	3.2	1.9

223a. Investigations on Turbine Oils. H. Stäger, *Internl. Congress Testing Materials, Amsterdam,* 1927. Vol. II, pp. 456-468.

Present test methods comprise only the testing of the oils as delivered and the quantities measured do not always include all of those pertinent to lubrication.

The theory of perfect film lubrication is relatively well developed, not so, however, that of semi-fluid lubrication. It has been found that a certain definite minimum quantity of oil is necessary to secure fluid lubrication. If this minimum amount is not present, the friction depends on the amount of oil that is present. In this case, the adhesive properties of the oil are of importance. Hence in the selection of a lubricant it is necessary to make capillary tests to get an idea of the adhesion, capacity for spreading, and behavior during semi-fluid lubrication. The most important researches on the properties of fluid films are those of Langmuir, Harkins, and their collaborators. Langmuir considers that the forces coming into play are physico-chemical forces, *i.e.,* primary and secondary valence bonds. These, Langmuir finds, are exerted in the highest degree by polar groups which cause the structure of the molecule to be asymmetrical. Harkins considers the strongest polar groups to be directed toward the adsorber (with lubricants, towards the metal). These forces increase with the molecular weight.

According to Dunstan and Thole, the lubricant molecules enter into a physico-chemical combination with the metal surface.

Bachmann and Brieger have determined the heat of wetting of a metal by a lubricant as a measure of the adhesion.

Evans has measured the potential difference between lubricated and unlubricated portions of a metal, which may possibly serve as a measure for the lubricating capacity of a lubricant. Similar observations have been made by Hackford in practical tests of Diesel engines.

The frictional force to produce damage to a lubricated bearing depends on viscosity, heat of wetting, and geometry of the bearing, according to von Dallwitz-Wegener, in the following manner:

$$F = \varphi \frac{\eta}{\epsilon \beta}$$

η = Viscosity.
β = Heat of wetting.
φ = Constant depending on radius, relative speed of lubricated parts, load, etc.
ϵ = Smallest distance between surfaces.

The heat of wetting, β, has been neglected in nearly all investigations of mineral lubricating oils. Duffing has proposed to determine this from the angle of contact. The angle of contact, however, depends not only on the oil, as is often assumed, but also on the surface it is in contact with. In general the angle of contact will be smaller, the wetting properties better, the greater is the cohesion pressure of the metal, but in the case of heterogeneous alloys, such as are used for bearings, the case is not so simple. In the case of bronzes, the bearing is run-in by abrading off any projecting points, while in the case of white metals, running-in occurs by yielding of the matrix.

The author investigated 12 oils, both as received and artificially aged by heating for 1000 hours in air at 112° C. The oxidation products formed were identical with those obtained in service. It was found that the viscosity had nothing to do with the force of adhesion. A white oil became more viscous after ageing but the angle of contact dropped from about 45° to about 28°, and the acid number increased from 0.12 to 6.5, showing that compounds with polar groups had been formed. The increased viscosity indicates a considerable polymerization, hence increase in molecular weight.

The alloys with respect to their wetting capacity may be divided into three groups: (1) Steel and cast iron, poorest; (2) red brass and bronze; (3) white metals with the best capacity for being wetted. With regard to these last, there is no appreciable decrease in wetting power when lead is substituted for tin. The wetting capacity was materially decreased by removing most of the acid compounds and those of the nature of petroleum pitch, by means of freshly calcined fuller's earth; in some cases it was decreased even below that of the original product. These active or polar groups, however, were not the only ones to be considered; in some cases the acid compounds could be removed without affecting the angle of contact and in other cases the angle of contact was materially lessened if they were partly removed. Further investigation was necessary to find out what compounds besides the already known fatty acids, were effective.

No appreciable difference was found in the lubricating properties of naphthene- and paraffin-base oils as delivered, but the naphthene-base oils were somewhat better as regards resistance to oxidation. The wetting capacity, and hence the capacity for film formation of an oil is improved by the oxidation products formed on ageing.

While a certain amount of decomposition of turbine oils is desirable, the reverse is true of capacity for formation of foam and

emulsions. Hitherto these properties have been regarded largely as functions solely of surface tension and viscosity and have led to the belief that less viscous oils of the same surface tension inclined to foam less. Quite different conclusions, however, have been drawn from recent investigations, in fact substances giving the most stable foams had the lowest viscosities. Ostwald and Steiner show that the foaming capacity depends neither on surface tension nor on viscosity and that substances with surface-active forces sometimes destroyed the foam. Bartsch, however, showed that this capacity was lost if the concentration of these substances exceeded a certain value. Foam formation is greatest when there is maximum heterogeneity in the surface layer, *i.e.*, equal numbers of molecules of solvent and foaming agent. The formation of such boundary layers is essential to foaming and the products formed during ageing give rise to just such layers. Heat and suspended oxygen also favor the formation of emulsions with steam and leakage water. Duckham and Bowery showed that emulsions containing 15-20 per cent water were not injurious to lubrication. It is certain that surface tension is no criterion for the capacity for forming emulsions, so that the proposals of Phillip, Dellbridge,[1030a] Conradson,[1038b] and Dimmig[1045b] are completely off the track, especially as the disperse phase may be oil or water according to the prevailing conditions. According to the investigations of Clowes, the equilibrium of the emulsion depends on the relative number of positive and negative ions. With mineral oils, under some conditions, there is no critical ratio, so that a pseudoequilibrium may arise, in which both kinds of emulsion exist together.

The author studied the surface tensions of the oils at his disposal against different solution as well as against acids, alkalies and pure water. One method of doing this is by studying the character of drops, the capacity for drop formation increasing with the surface tension. The author's investigation showed that surface tension was no criterion for emulsification which is understandable from the results of Clowes' investigations on equilibrium and ion adsorption. In this case, the development of the surface layer and its structure, *i.e.*, the formation of polar groups, plays the principal part. With water, emulsions of the water in oil type were formed, while with soda solutions, they were of the inverse type. Emulsions of the first type were easily destroyed by the application of an electric potential, while those of the inverse type were extraordinarily stable.

Studies were made of emulsions by Clayton's conductivity

method.[986] In most cases the conductivity did not change appreciably between 20 and 85° C. The acid number is not a satisfactory measure of the decomposition of an oil by oxidation, neither is it correlated with the reduction of surface tension and the capacity for forming emulsions. In certain cases, emulsions may be formed with pure water.

224. Oil Flow in Plain Bearings. D. P. Barnard, 4th, *Ind. Eng. Chem.*, 18:460-462 (1926). 6 Figures.

Oil-film thickness, friction loss, temperature, and oil consumption are definitely related to the path of oil flow through the bearing and therefore to the rate of flow. The usual course of the lubricant is as follows. The oil enters at a point halfway between the ends of the bearing, where it is picked up by the revolving journal and dragged through the load-supporting part of the oil-film space. The pressure thus developed serves to support the bearing load and also to force the lubricant towards the ends of the bearing. All of the oil eventually escapes from the ends due to the pressure generated within the film and to oil-feed pressure. The effect of these two pressure components must be considered separately.

Flow Due to Pressure Developed in the Oil Film. As the motion of the journal carries oil only in the direction of rotation, end leakage must be entirely due to pressure. The clearance is so small that the flow, particularly the end flow, is laminar and must obey Poiseulle's law, from which follows:

$$\text{Rate of flow (cu. in. per sec.)} = \varphi[P(dc)^2/\eta l]$$

where

$P = $ load on bearing.
$d = $ diameter of bearing.
$c = $ clearance between bearing and journal.
$l = $ length of bearing.
$\eta = $ absolute viscosity of oil.

The pumping efficiency is the ratio of the volume discharged per revolution to the clearance volume, accordingly:

$$E = \frac{\Phi \dfrac{P(dc)^2}{\eta n l}}{\dfrac{\pi d c l}{2}}$$

As E is dimensionless it may be expressed as a function of dimensionless ratios as follows:

$$E = \varphi\left(\frac{P}{\eta n}\right), \left(\frac{d}{l}\right), \left(\frac{c}{l}\right)$$

Effect of Oil-Feed Pressure. This also follows Poiseulle's law, but as it changes with changes in the relative positions of journal and bearing, no general expression for the effect of feed pressure can be formulated. The range of feed pressure, however, is rather low and is readily covered by experiment.

Experimental Results. Experiments were made on a bronze bearing supported by a hardened steel shaft within the following ranges of the variables: viscosity = 12.5-43.5 centipoises; angular speed = 200-2000 revolutions per min.; load = 41-271 pounds per sq. in.; diameter = 1 in.; length = 2 in.; clearance = 0.006-0.0011 in.; oil-feed pressure = 10-70 pounds per sq. in.; oil flow = 0.075-3 cu. in. per min.

Curves of pumping efficiency against $\frac{\eta n}{p}$ are given for different oil feed pressures. The drop in pumping efficiency with increase in $\frac{\eta n}{p}$ is to be expected, as under these conditions the journal occupies more nearly the center position, and as less presure is generated in the film itself, the tendency is for the oil to follow more closely the direction of rotation. (As part of the flow is due to feed pressure the recorded values are not true pumping efficiencies. No measurements were made under conditions of zero feed pressure, though an extrapolated curve for this condition is given.)

Of course the method fails at the point of fluid film rupture and the experimental data do not include this point.

Effect of Clearance. Pumping efficiency is apparently not dependent on clearance, so that the total flow varies with the clearance.

Oil Grooves. The author states the results found by extrapolation for zero oil feed pressure would apply to any plain bearing with an oil groove on the unloaded side. The effect of grooving on the loaded side is open to speculation. It is well known that such grooves are almost certain to diminish the load capacity.

A motion picture study was made of the oil flow in a plain bearing of glass, the path of flow being made visible by a small amount of dyed glycerol solution. The effect of reducing $\frac{\eta n}{p}$ is to lessen the ability of the journal to carry lubricant through the load supporting part of the film space.

In general, increasing $\frac{\eta n}{p}$ increases film thickness, although the pumping efficiency is lowered. If there are no adequate means for heat

dissipation by metallic conduction, problems may arise in securing a satisfactory film thickness. This will be aided by large clearances and high feed pressures.

225. The Theoretical and Practical Study of Lubrication. H. Havre, *Genie Civil*, 90:45-48. [Abstract in *Mech. World*, 82:397 (1927).]

"The author remarks that what is aimed at in lubrication is the reduction of the coefficient of cleavage of the oil $\frac{n\eta}{p}$ whilst maintaining adherence between the metal surfaces and the surface of the lubricant in contact with them.

"The two most important qualities of a lubricant are: (1) viscosity, or the attraction of molecules of oil for each other;* (2) 'oiliness' or a tendency to adhere to a solid surface—adhesiveness. It gives rise to a velvety sensation when oil is rubbed between the finger and thumb, adhering even when they are separated vertically. As no mutual attraction exists between metals and either water, mercury, or glycerine, the latter are unsuitable for bearing purposes. A drop of mercury placed between and in contact with two metallic surfaces appears to be repelled, its edges bulging outwards; a drop of oil seems to be drawn out between the surfaces and its edges are concave. A sort of condensation of oil molecules, accompanied by a slight rise in temperature, occurs in the surfaces in contact with the metal, and is equivalent to a considerable apparent local increase in viscosity, the molecules forming a more rigid film than when completely surrounded by liquid oil. Adhesiveness is evidently desirable, and it is found that vegetable oils, especially fatty acids, considerably increase the oiliness of petroleum lubricating oils; hence the customary addition of 0.5 per cent of stearic acid or 1 per cent of rape oil. Oils have a particular attraction for sulfides, graphite and coal. Hence it has been proposed to sulfurize the surface of journals and bearings. The current practice of applying flour of sulfur to bearings which are liable to overheat causes the formation of hydrogen sulfide which increases the adherence of the oil. Graphite, which has a considerable adhesiveness for both metal and oils, perhaps causes a resistant film to form on the parts in contact. Forcing oil between surfaces causes great waste from overflow, but is otherwise effective, and the addition of a little fatty acid

* Viscosity is chiefly kinetic, i.e. due to transfer of momentum.—Ed.

or the sulfurization of rubbing surfaces by exposure to hydrogen sulfide is recommended. Thick greases formed at high temperatures from animal fat with soda form very resistant films and are unsuitable for lubrication. Rough surfaces tend to break the adhering film, and should be polished. Adhesiveness is coincident with a tendency to spread, and is evidently a surface tension phenomenon, different metals having attractions for oil similar to those due to surface tension. The author illustrates this by a diagram. Turbines should not be supplied with a lubricant which tends to form an emulsion with water. This is generally due to the formation of metallic soaps in the presence of mineral acids. An oil which is viscous but only slightly adhesive is a bad lubricant; an oil slightly viscous but very adherent is an excellent lubricant".

226. Water as a Lubricant for Machinery Bearings. C. W. Naylor, *Trans. Am. Soc. Mech. Eng.*, 27:432-433 (1906).

Two jack shafts, 5 in. diameter by 18 ft. long, transmitted 175 horse-power each at 250 revolutions per min. through leather belts to 5 generators. The boxes were 14 in. long of the plain non-self-oiling type, and split in the horizontal plane. The pull of the six belts was all in the same direction and horizontal.

For two years much trouble was experienced keeping the boxes cool with oil. Several grades of oils and greases were tried. Finally Lake Michigan water was tried and was used with good results for eleven years, the set being in operation ten hours per day. Five minutes before closing down small streams of oil were admitted to the bearings to prevent rusting overnight. The wear in eleven years was one-quarter in. for the box and nil for the shaft.

227. An Apparatus for the Investigation of Oils and Bearing Metals. G. Dettmar, *Elektrotech. Z.*, 23:741-745 (1902).

The author has designed a simple and accurate machine especially adapted for testing oils. A complete test may be made in 20 minutes. He refers to earlier experiments (*Elektrotechnische Zeitschrift*, 1899, Nos. 22 and 23).

Oils are tested under conditions approximating those of service, *i.e.*, in a thickness of 0.05-0.1 mm. The machine consists essentially of a shaft on which two flywheels are mounted and which is supported by a ring oiled bearing. The machine is set in motion and the energy lost may be determined at any moment from its loss of angular

velocity. The machine runs from 5-15 minutes. The load on the bearing is about 3 kg./cm.² The author states that the friction is independent of the load. The initial speed is 2000 revolutions per min. or 3.14 meter/sec. (30 mm. diameter.) Tests were started when the temperature became steady. A heating coil was used for preliminary warming up as it would take one or two hours to reach constant temperature by running alone.

The author takes the frictional constant of two oils to be inversely as their time of running in his machine. The quantity of oil required is about 0.3 liter.

In a previous investigation the author found the coefficient of friction to be proportional to the square root of the lineal speed, but the present research shows that the exponent of speed is not always one-half but varies from 0.55 at 28° to 0.39 at 70° C. If the lineal speed is below 0.1-0.2 meter/sec. the coefficient increases again. In the previous work, coefficient of friction was found inversely proportional to the load but now this is found to be true only for a completely enclosed bearing. Experiments with different size shafts in the same bearing show that the coefficient of friction is inversely proportional to the thickness of the oil film. In a full bearing the film of oil becomes thinner below and thicker above when the shaft is loaded, making the average the same, therefore the force of friction should be independent of the load. If a film is interrupted the upper half of film does not become thicker even if the lower half becomes thinner (assuming that the upper half is not forced down upon the shaft), therefore the force of friction increases. Data from full and half bearings confirm this.

The thickness of oil film is of great importance in investigations on bearing metals. As the film is only 0.025 to 0.050 mm. thick, the bearing must be accurate to 0.001 mm. to obtain accurate results. Such accuracy is rare. If a full bearing is used, data are not so reliable as when only a half or quarter bearing is used. If the same oil is used the film thickness depends on the load.

The author finds that the effect of the bearing metal on the friction is relatively small at speeds under 1 meter/sec.

Thermal conditions are of great importance. The higher the temperature, the greater is the allowable speed (assuming complete lubrication). Author confirms Tower's results on the effect of temperature. He finds that for a given angular speed the coefficient of friction is nearly inversely proportional to the temperature.

Curves of coefficient of friction against lineal speed are given.

These show a minimum coefficient at about 0.2 meter/sec. For zero speed the coefficient has a finite value. Above 0.2 meter/sec. the coefficient is proportional to the speed.

The author explains the shape of the curves by: (1) the slip of oil with reference to the metal at low speeds, and (2) a stationary layer, therefore pure fluid friction, at high speeds. A minimum coefficient of friction is shown by a point of inflection in the revolutions per min. *vs.* time curve. The author gives curves for white metal and red bronze bushings.

Experiments indicate that the total time of running down may be taken as an index of the internal friction of the oil. Curves for two different bearing metals practically coincide in the upper part of the range, but diverge greatly in the lower part. Curves for six different oils are given.

228. **Bearing Metals. Notes Regarding Methods of Testing and Qualities.** R. C. Carpenter, *Trans. Am. Soc. Mech. Eng.,* 27:422-425 (1906).

The author states that there are no laboratory tests which are likely to bring out all the qualities of a bearing metal. The Thurston machine gives the coefficient of friction with substantial accuracy, but exaggerates the heating effects. The results also depend more on the lubricant than on the bearing metal.

The author has used the admittedly highly artificial method of applying a known quantity of oil to the shaft and noting the temperature and coefficient of friction at stated intervals. The temperature and pressure at which seizure occurs may also be used as an index of the value of a bearing metal.

The bearing metal should have considerable adhesion for the lubricant, it should be softer than the shaft but hard enough to retain its shape, while if melted it should not adhere to the journal. The alloy Pb, 85; Sb, 15 is too soft for hard service. Genuine babbitt has proved to be adapted to a wider range of service than any other material. Lead is a poor conductor of heat, therefore alloys containing much lead run a good deal warmer.

The alloys Zn-Al-Cu, with zinc the largest constituent, were satisfactory in some cases but were much affected by impurities in the zinc. The alloy Al, 50; Zn, 25; Sn, 25 has many excellent properties for certain types of bearings.

229. **The Electrical Resistance of Bearings.** A. E. Kennelly and
C. A. Adams, *Elec. World Eng.*, 41:231 (1903).

The authors found that there was considerable resistance between
the shaft and pedestals of small dynamo machines while the shaft was
rotating. This resistance was maintained over a wide range of speeds,
but broke down at speeds low compared with normal.

On an Edison bipolar 125 v., 6 kw. machine operating at 1800
revolutions per min., the resistance was practically nil when the shaft
was at rest. At speeds above 100 revolutions per min. the short circuit
in the bearing disappeared and the resistance of both bearings in
parallel rose to 4.4 megohms. Each bearing was 5 in. long by 1.125 in.
internal diameter. The resistance was then 1000 megohms per sq. cm.
of oil surface. The bearings were self-oiling types with two brass rings
in each.

The insulation was maintained under considerable lateral pressure,
this having to be altogether abnormal to break down the insulation.

The insulation broke down if any of the rings accidentally made
contact with the sides of the bearing slots. The insulation was not
restored until all rings were set in motion again.

Similar experiments with a new machine in which the bearing
surfaces were not yet worn to normal condition showed only a more
limited degree of insulation.

If the brass rings were replaced by fiber ones of the same dimen-
sions the insulation did not break down even when 600 volts D.C. was
applied. Resistance was markedly reduced when 1670 volts A.C. was
applied.

230. **Some Experiments in Lubrication.** (Correspondence.) A. V.
de Forest, *Engineering*, 101:509 (1916).

Measurement of the electrical resistance of an oil film might offer
a delicate index of the lubrication of a bearing. A milliammeter and
a resistance box were connected through the bearing to a dry battery.
Resistance was chosen to give full scale deflection of the instrument
on the short circuit of the bearing.

First experiments were on a circular brass disk 2 in. in diameter
bearing on a polished cast iron plate. With fairly heavy oil the resist-
ance varied from 0 to 100 ohms with pressure. Thin oil decreased the
resistance of films. Sudden changes in resistance took place when the
plates were left untouched. If left in contact, they were separated in

a few minutes by thin sperm oil. The continuous oil film formed was very sensitive to slight vibrations and even sounds.

The resistance of the bearings of a grinder was measured. This was very variable on starting, but at full speed was fairly uniform. Resistance was lowered by an increase in the load.

Many other tests were made. Excessive load, poor fit or lack of oil were indicated by short circuits.

231. Measurement of Oil-Film Thickness in Bearings. V. Vieweg, *Verkehrstech.*, 1927, p. 858. (Abstract by Przygode.)

The author describes various methods for measuring oil-film thickness. In a new method devised by him, the bearing, if perfectly lubricated, is made to act as an electrical condenser, the conductors being the journal and bearing metal, and the dielectric being the oil. The film-thickness is found from the capacity of this condenser as measured by an alternating current bridge. The method is applicable also to ball and roller bearings.

232. The Experimental Determination of the Relative Value of Short Bearings. Editorial Correspondence, *Am. Machinist*, 28(2):878-879 (1905).

It is a fundamental assumption of bearing design, that, other things being equal, the load capacity is directly proportional to the length. So far this has never been doubted, but some experiments carried out by Hayward for the Link Belt Engineering Company show that under the conditions to which chain links are subjected this is very far from being true. The small unit loads to which chain links could be subjected without destructive wear has long been a puzzle. This was true for loads less than the working loads of bearings in general.

A special design of the above company has pins and links possessing much greater bearing length on the surfaces which take the load. About twice the surface of the ordinary design is brought into play. The load capacity, however, is far in excess of twice that of the ordinary design, leading to the conclusion that the load capacity increases faster than the length.

Tests were made in a special machine of bearings having different lengths. These were run dry (without oil) until the longest diameter of the hole was 1.5 times that of the pin. Curves are given showing that the life of bearing increases faster than the length. The explana-

tion of this seems to be in the feathers which form on each side of the bearings. The layers of metal on the outside have nothing to support them and spread out under the load. The shorter the bearing, then, the greater the reduction of effective area. The effect of length of bearing on the unit load capacity was still pronounced in steel bearings when the length was 3 times the diameter.

233. Bearing Testing. E. vom Ende, *Verkehrstech.*, 1927, p. 858. (Abstract by Przygode.)

The author discusses the design of bearings, bearing friction, and materials of journal and bearing, as well as oil. The principal characteristics to be determined are the temperature-load, and temperature-speed curves, though it is also desirable to determine the moment of friction curve. Well adapted for this are the Kammerer testing machine and the new Vieweg machine, both of which may be used in the factory.

234. The Bearing Testing Machine of the Reichsbahn Versuchs-anstalt at Göttingen, Germany. Przygode, *Verkehrstech.*, 1927, p. 858.

A one-fifth scale model of the Reichsbahn bearing testing machine was exhibited at the Materials Exposition in Berlin, Oct., 1927. This machine allows bearings to be tested complete in a railroad car-frame equipped with axle and springs under conditions as near as possible to service conditions. The input to the driving motor is measured and also the temperature rise in the bearing. Side pressures may also be applied. The Reichsbahn exhibit included a collection of bearings showing the development up to the present day. The present type comprises a red brass back in a cast steel shell, the red brass being lined with Bahn-metal or a lead-alkali metal alloy. In early bearings the pressure was high at the ends, but in recent types it is distributed uniformly over the whole length.

PART 4

TABLES SHOWING PROPERTIES OF BEARING METALS

TABLE 1.—*Brinell Hardness of Slowly Cooled Lead Bronzes.**

Per Cent Sn	Per Cent Pb	BHN	Per Cent Sn	Per Cent Pb	BHN
4.5	0	49	4	6.9	46
8.8	0	63	8	6.9	59
16.3	0	77	13.9	7.0	80
25.9	0	230	2.4	10.6	39
0	10	27.2	8	10.4	48
0	20	23.8	13.9	10.4	86
0	40	13.8	4.1	14.12	39
4.1	0.95	57	9.2	15.3	57
8.1	1.1	67	19.8	5.0	130
14.1	1.15	83	20.4	8.8	130
3.9	3	46	21.5	8.05	150
7.8	3.2	61	11.0	5.0	70
13.9	3.1	83	17	5.0	109
3.99	5.0	46	5	20	44
8.0	5.0	61	24	5	182
13.7	5.1	93	12	20	70

* Giolitti and Marantonio, *Gazz. chim.*, 40(1):51-77 (1910).

TABLE 2.—*Properties of the A.S.T.M. Bearing Bronzes.*

| | Per Cent Composition | | | | | | Pounds per Sq. In. | | | |
No.	Cu	Sn	Pb	Maximum Zn	P	Maximum S	Maximum Total Impurities	Tensile Strength	Compressive Deformation Limit†	Per Cent El	BHN 500 kg. per 30 sec.
1	85	10	5	0.25	0.70 min.	0.05	0.50	28,000	18,000	12.5	60
2	80	10	10	0.50	0.70 min.	0.05	0.75	25,000	15,000	8	55
3	80	10	10	2.00	0.05 max.	0.05	2.50	22,000	12,500	8	50
4	77	8	15	0.50	0.25 max.	0.05	0.75	20,000	12,000	10	48
5	73	7	20	0.50	0.05 max.	0.05	1.00	18,000	11,000	7	45
6	70	5	25	0.50	None	0.05	1.00	15,000	10,000	5	40

Unlisted max.

Permanent set in one in. at 100,000 psi.

A	*	20 max.			1.0 max.		0.50	24,000	0.06–0.12 in.		
B	*	17 max.			1.0 max.		0.50	18,000	0.10–0.20 in.		

* Remainder. In Nos. 1 to 6: Fe is limited to 0.25 per cent; Sb to 0.50 per cent; and Al is excluded.

† Defined as the load that produces 0.001 in. compression in a specimen 1 in. long and 1 in. square cross-section.

Permissible variation in specified percentages (except of impurities): not over 5 per cent specified—0.50; over 5 per cent to 10 per cent specified—0.75; over 10 per cent specified—1.50.

In the foregoing tables, Nos. 1-6 have the compositions specified by American Society of Testing Materials specification B31-21 for bronze bearing metal in ingot form; the data on strength indicate what may be expected of material properly handled. Grades 1 and 2 are phosphor bronzes. The last two grades (5 and 6), which are liable to segregation of lead, are improved by 1 per cent nickel. For railroad use, metal similar in composition to Nos. 2 and 3 is specified for eccentric straps, cross-head gibs, etc., and similar to No. 6 for tender, freight and passenger car equipment. Alloys *A* and *B* are specified (B22-21) as to both composition and properties, for turntables and swing and lift bridges. They illustrate the choice of bearing metal according to the material of the moving part: *A* is suited to contact with hardened steel discs at pressures over 1500 psi (turntables, swing-bridges); *B* is suited to contact with slow-moving soft-steel parts at lower pressures (trunnions and journals of lift bridges).

TABLE 3.—*Properties of Alloys for Car Journal Bearings.* [*]

Cu	Sn	Pb	Zn	Tensile Strength, psi.	Per Cent Elongation on 2 in.	Scleroscope Hardness	Compressive Proportional Limit, psi.	Per Cent Compression [†]
95	5	0	0	41.800	34.5	23	18,000	31
90	5	5	0	40,500	34.5	15	19,000	32
90	10	0	0	39,000	15	23	25,000	26
85	5	5	5	38,150	36	14	18,000	33
85	5	10	0	31,200	19.5	14	18,000	36.5
85	10	5	0	32,700	9.5	19	22,000	26
80	5	5	10	28,100	15	16	18,000	32
80	5	10	5	34,700	23	18	16,000	34
80	5	15	0	23,300	15.5	14	16,000	39
80	10	5	5	33,550	3.5	21	27,000	21
80	10	10	0	31,850	8.5	21	23,000	29
75	5	5	15	27,000	10	18	17,000	28
75	5	15	5	31,350	19	19	18,500	..
75	5	10	10	29,800	13	18	19,000	32
75	5	20	0	23,300	15.5	12	15,000	..
75	10	5	10	24,400	1.0	25	27,000	19.5
75	10	10	5	31,300	2.5	21	28,500	22
75	10	15	0	27,000	6	15	23,000	32
70	5	25	0	24,750	14	12	16,500	..
70	5	10	15	28,400	10	20	18,500	30
70	5	20	5	28,100	20	15	17,500	..
70	10	20	0	27,000	6	19	21,000	..
70	10	5	15	27,500	1.5	28	40,000	17
70	10	15	5	30,000	4.75	22	26,000	..
70	10	10	10	28,100	1.5	23	29,000	17
65	5	30	0	19,800	12	10	15,000	..

[*] G. H. Clamer, *Trans. Am. Inst. Metals*, 9:241-263 (1915).
[†] Compressive stress = 100,000 psi. (pounds per sq. in.).

TABLE 4.—*Wear Tests on Bronze Bearing Metals.*[*][†]

Per Cent Composition				Temp. Rise, °C.	Wear, milligrams	Relative Wear [‡]
Cu	Pb	Sn	Zn			
95.0	...	4.95	...	29	5.03	0.49
90.7	...	9.45	...	28.5	11.45	1.13
85.8	...	14.9	...	28	18.14	1.79
90.8	4.8	4.6	...	29.5	3.51	0.35
85.1	10.6	4.6	...	31	2.46	.24
81.3	14.1	5.1	...	32	2.12	.21
75?	20?	5?	...	32	1.80	.18
68.7	26.7	5.2	...	32	1.32	.13
64.3	31.2	4.7	...	35.5	0.84	.08
83.3	10.3	5.3	2.1	38	2.69	0.27
79.8	10.3	4.7	5.4	36.5	3.02	.30
77.4	11.4	5.6	6.5	38	3.06	.30
74.3	10.5	4.7	11.0	38.5	5.48	.54

* Tests made on the Carpenter friction testing machine. Total number of revolutions = 100,000; speed = 525 r.p.m.; bearing 3½ in. long by 3¾ in. diameter; load = 1000 lbs. per sq. in.; lubrication = Galena coach oil fed by cotton waste.

† G. H. Clamer, *Trans. Am. Inst. Metals,* **9**:241-263 (1915).

‡ Comparison with the work of Dudley (Abs. 1) on the basis of the work of Portevin and Nusbaumer (Abs. 99) according to whom the wear of copper-tin bronzes is proportional to the tin content, or more exactly to the amount of "delta" constituent in the alloy.

TABLE 5a.—*Lead-Tin-Antimony Alloys with Additions.*

No.	Pb	Sn	Sb	Cu	Bi	Designation and Information in Sources	Source
						Group A with Low Tin Content.	
1	65	...	25	10	...	Locomotive and tender bearings, Cie. de l'Est	Charpy
2	78.28	1.25	20.12	0.7	0.28	....	Buchanan
3	80.65	11.4	7.53	0.42	...	Soft white metal	Fairlie
4	78.0	5	15	2	0.25	For eccentric linings	Buchanan
5	72.0	11.5	13.5	3	...	Locomotive bearings, withstands compression, but not pounding on reversal of motion	Hughes
6	77	10	12.5	0.5	...	....	Campbell
7	77	8	14	1.0	...	Bearings such as "Coleco"	Campbell
8	60	32	3	5	...	Eccentric strap linings, piston-rod packing, Cie. de l'Ouest	Charpy
						Group B with Medium Tin Content.	
9	44.25	34.74	17.1	3.92	...	....	Buchanan
10	33	53	11	3	...	Shall melt at 146° *	Buchanan
11	38	42	17	3	...	For metallic packing	Buchanan
12	48	40	10	2	...	Underwater bearings	Buchanan
13	44	34	16	6	...	Main bearings	Buchanan
14	44	35	17	4	...	Marine bronze No. 4	Buchanan
15	34.0	54	11	1	...	Locomotive bearings, somewhat harder than No. 5	Hughes
16	48	40	10	2	...	....	Campbell
17	46	36.5	16.5	1	...	American railroad	Campbell
18	33	53	10.6	2.4	Zn, 1	....	Roberts-Austen
						Group C with High Tin Content.	
19	6.25	84	2.15	7	...	This alloy is given preference over those richer in lead because it segregates less †	Kern
20	17	76	3	3	...	....	Buchanan
21	12	80	...	6	...	Plastic Metal	Buchanan
22	10.5	70	15	9.25	0.25	Plastic Metal 1	Buchanan
23	12	80	...	8	0.5	Plastic Metal 2	Buchanan
24	17	77	3	3	...	For marine engines	Buchanan
25	13.50	74.22	6.55	3.6	Zn, 1.8	Axle boxes	Buchanan
26	14.75	78.84	Traces	3.7	...	Acid-proof metal	Buchanan
27	10	80	1	8	Zn, 1	Plastic Metal	Buchanan
28	17	77	7	6	...	....	Buchanan
29	10	80	2	7	1	Plastic Metal	Buchanan
30	10	75	12	3	...	....	Campbell

* Incorrect, melts above 230° C. End of solidification at 180° C.
† Segregation may also be prevented in the least rich alloys by addition of copper.

TABLE 5.—*Lead-Tin-Antimony Alloys Without Additions.*

No.	Per Cent Composition Lead	Tin	Antimony	Freezing Begins °C.	Ends °C.	Tendency to Segregate	Ball Hardness $P_{0.05}$ kg.	Impact Compression Test a_r cm.kg/cm³	Compression Test m kg/mm²	ϵ Per Cent	σ 2% kg/cm²	Designation and Information in the Literature	Source
1*	94	..	6	285	245	No	15	>1000	6.5	>50	400	For caulking bell joints in water pipes	Dudley
2*	92	..	8	260	245	No	15	>1000	6.0	>50	400		Hughes
3*	88	..	12	250	245	No	16	700	9.5	>50	550	....	Dudley
4†	87	..	13	245	245	No	16.5	700	10.0	>50	560		Dudley
5	85.4	..	14.6	260	245	Little	17	600	10.0	>50	590	Car bearings	Dudley
6	85	..	15	267	245	Yes	17	600	10.0	>50	600	Soft bearing metal	Hiorns, Dudley
7	84	..	16	272	245	Yes	17	500	10.5	>50	600	For slowly running rolls	Ledebur
8	83.5	..	16.5	275	245	Yes	17	500	10.5	>50	600	Magnolia metal	Dudley
9	78.4	1% Zn	19.6	300	245	Yes	18	400	11.0	>50	620	American friction bronze	Dudley
10	77	0.6% Fe	23	320	245	Yes	19	400	11.5	42.5	640	Formerly used in place of No. 13, was not as good	Kern
								Group A with Low Tin Content.					
11*	90	2	8	268	242	No	15	>800	9.0	>35	530	Russian railroad car bearings	Lake
12*	87	6	7	268	242	No	15	>600	11.0	>35	570	Heavily loaded bearings	Lake
13*	72	21	7	246	184	No	17	>700	11.3	>35	515	For bedding heavy parts of marine engines	Kern
14*	85	5	10	250	242	No	18	700	12.4	>35	700	Jacoby metal	Lake
15	62	27	11	243	184	Yes	18	800	12.7	30	600	....	Campbell
16	82	2	16	275	242	Yes	19	500	12.0	>45	700	Metallic packing, Cie de l'Est	Campbell
17*	89	12	8	252	184	No	20	>600	13.7	35	700	Eccentric strap linings and bearings, Cie. de l'Est	Charpy
18†	70	20	10	234	184	No	20	700	13.0	>35	650		Charpy
19*	83.3	8.3	8.3	255	184	No	20	>600	12.6	>35	700		Campbell
20	80	4	16	275	242	Yes	21	500	13.3	>45	780	Hard mixture for tunnel bearings of ships	Buchanan
21	80.5	4.5 0.5% As	14.5	266	242	Yes	21	500	13.3	>45	780	Bearing such as "Glyco"	Campbell
22†	76	14	10	239	184	No	22	700	14.9	35	730	Metallic packing and linings, Cie. d'Orleans	Charpy

(Columns 6–9 under heading: *Rapidly Cooled Alloys (Condition K) at Room Temperature*)

No.												Remarks	Investigator
23	80	5	15	269	242	Yes	22	500	13.9	>45	815	Good bearing metal, also Magnolia	Sperry
24	78	6	16	275	242	Yes	22	450	15.0	45	850	Bearing such as Magnolia	Campbell
25	78.3	3.9	17.8	287	242	Yes	22	450	13.5	42.5	800	Magnolia	Stanley
26†	80	10	10	242	242	No	22.5	600	15.0	35	815	Magnolia	Lake
27	70	17	13	245	242	Yes	23	500	15.0	35	800	For metallic packing	Hughes
28	70	5.9	16.8	279	242	Yes	24	500	15.0	37.5	870	Magnolia and Tandem	Thurston
29	77.7	15	15	261	184	Yes	26	450	16.1	30	900	Not so good as No. 13	Kern
30	70	5	24	325	242	Yes	26	300	16.0	30	890	Standard white metal	Lake
31	71	5	17	278	242	Yes	26	450	15.9	35	910	....	Campbell
32	76	7	15	262	242	Yes	27	450	16.5	30	930	Piston-rod packing Cie. de Nord	Charpy
33	73	12	15	273	242	Yes	27	400	17.0	30	950	Graphite metal	Dudley
34	68	15	17	265	242	Yes	27	450	16.4	30	930	Railroad bearings	Lake
35	75	10	15	297	184	Yes	28	200	18.0	30	980	Railroad bearings	Ledebur
36	60	20	20	286	242	Yes	28	400	16.9	30	970	American railroad bearings	Campbell
37	73.5	8	18.5	289	242	Yes	31	300	17.7	27.5	1030	Cie. de l'Est, 1893	Guillet
38	65	10	25	325	242	Yes	31	200	20.0	15	1135	Graphite metal	Lake
Group B with Medium Tin Content.													
39	56	36	8	231	184	Yes	14	>800	12.0	32.5	500	Metallic packing	Buchanan
40	50	40	10	241	184	Yes	15	800	13.4	32.5	510		Sperry
41	46	42	12	255	184	Yes	16.5	750	14.7	35	640	Lining metal	Buchanan
42	42	46	12	255	184	Yes	17	800	15.0	40	650	Hogles metal	Hierns
43	44	44	12	255	184	Yes	17	800	15.0	37.5	640	Better mixture than No. 20	Buchanan
44	42	42	16	275	184	Yes	20	500	17.2	30	760	Axle bearing, French National Railroad	
45	40	45	15	271	184	Yes	20	600	17.0	35	740	Axle bearing, French National Railroad	Ledebur
46	50	35	15	271	184	Yes	20	450	15.9	25	735	Good bearing metal	Ledebur
47	37	38	25	321	184	Yes	30	300	23.0	15	1100	Italian railroad	Brass World / Thurston
Group C with High Tin Content.													
48	10	75	15	279	184	Yes	26	>1000	20.0	30	830	Bearing metal	Campbell
49	5	75	20	309	184	Yes	28	>1000	22.7	25	930	For small castings	Campbell
For Comparison:—Stock Bearing Metal.													
50	Cu 5.43	83.1	11.1	{Rapidly cooled}			26	1188	23			Railroad bearings	Heyn and Bauer
				{Slowly cooled}			21	250	17				

*† The values in columns 3–9 are inserted on the basis of the investigations carried out. The alloys marked * lie below the line E_2b_2, G (Fig. 2). They are composed accordingly not of freely separated, hard crystals embedded in a softer matrix, but of soft crystals embedded in a harder matrix. The alloys marked ‡ are composed only of matrix without embedded crystals. ‡ The values σ 2% mean the compressive stresses occurring for a decrease in height of 2 per cent in the test pieces under investigation.

TABLE 6.—Effect of Pouring and Mold Temperatures on Pb, 83.1; Sb, 12.1; Sn, 4.8 (Ellis).

Speci-men No.	Mold Temp. °C.	Pouring Temp. °C.	Total Cool-ing Time	Freez-ing Time	$\frac{1}{\text{Cool-ing Time}}$	Freez-ing Rate °C. per sec.	Per Cent Compression Under Compressive Stresses* of:									Compressive Stress* at Rupture,	Per Cent Compres-sion at Rupture,
							1275	2550	3825	5100	6375	7650	8925	10200	11475		
1	0	300	21	...	0.048	...	...	...	...	...	...	...	...	1.83	P.F.	†	...
2	0	350	22	...	0.045	...	...	...	...	0.14	0.35	0.50	1.03	1.45	"	†	38.53
3	0	400	23	...	0.043	...	...	...	0.02	.14	.32	.66	.87	1.32	"	†	33.16
4	0	450	26	...	0.038	...	...	...	...	.17	.34	.87	.96	1.15	"	†	34.86
5	0	500	32	...	0.031	...	...	...	.07	.14	.22	.47	.82	P.F.		†	37.61
6	100	300	36	...	0.028	...	...	.02	.06	.11	.28	.55	1.14	"		19,100−	36.03
7	100	350	38	...	0.026	...	.02	.04	.09	.19	.41	.72	1.23	"		20,375+	32.55
8	100	400	42	...	0.024	...	.04	.08	.08	.18	.34	.58	1.01	"		19,100+	35.10
9	100	450	51	.01	0.020	...	.01	...	.03	.18	.31	.52	.82	"		20,375+	30.20
10	100	500	68	...	0.015	...	...	...	.03	.13	.32	.59	1.01	"		19,100−	30.22
11	200	300	130	113	0.008	0.089	...	...	.03	.06	.25	.58	.90	"		19,100+	28.5
12	200	350	150	128	0.007	0.007	...	...	.03	.14	.39	.77	2.01	"		20,375+	32.1
13	200	400	190	152	0.005	0.066	.01	.03	.21	.35	.75	1.79	P.F.	"		16,575+	21.1
14	200	450	260	192	0.004	0.052	...	.03	.03	.12	.32	.67	1.39	"		14,025	...
15	200	500	360	240	0.003	0.042	.01	.10	.27	.52	.59	†	...			11,475	†

P.F. = plastic flow.
† = collapsed due to internal pipe.
* In pounds per sq. in.

TABLE 7—*Properties of White Metals.*§

No.	Per Cent Composition				Tension		Compression		BHN‡	Remarks on Properties and Applications
	Sn	Pb	Sb	Cu	UTS‡	El	YP‡	CS‡		
1	93	0	3.5	3.5	11.5	11.5	8.0	33.0	24.9	Combine maximum toughness and strength. For aero main and connecting-rod bearings.
2	86	0	10.5	3.5	14.9	7.1	9.8	38.6	33.3	Aero and auto main bearings.
3	83	4	10.5	2.5	12.5	0.0	9.6	39.5	34.5	Resistant to shock in spite of zero elongation. Aero and auto engines.
4	80	6	11	3	12.8	0.0	10.4	39.2	32.1	Heavy loads and high speeds, Diesel, turbines, rolling mills, locomotives.
5	60	28.5	10	1.5	11.3	0.0	8.3	28.8	27.1	Internal combustion engines, steam engines, dynamos, locomotives.
6	40	48.5	10	1.5	10.3	0.0	8.2	25.3	21.8	Heavy loads and medium speed or moderate pressure and high speed. Auto engine, railroad and street cars.
7	20	63.5	15	1.5	12.3	0.0	9.0	27.4	31.3	Medium pressure and speeds, light pressure and high speed.
8	78	0	11	11	14.3	0.0	10.2	40.0	37.0	Plastic metal. Lead is sometimes added. Used by mill and marine engineers for repair jobs, owing to long solidification range, it is capable of being spread as in a "wipe-joint."
9	5	80	15	0	10.5	2.8	8.0	29.9	24.9	Magnolia metal. Bi sometimes added. Has strength at high temperatures.

§ Mundey, Bisset and Cartland. *J. Inst. Metals*, 28:141-183 (1922).
* Pouring temperature about 350° C., mold temperature about 100° C.
‡ Stresses in thousands of lbs. per sq. in. Compressed to half of original length.
‡ 10 mm. ball, 500 kg. load.

TABLE 8.—*Properties of Tin-Base White Metals.*†

No.	Sn	Sb	Cu	Pb	Pour. t °C.	Ann. t °C.	BHN	d	h 10⁻³	UCS‡
	— Per Cent Composition —									
1	90.83	4.07	3.78	1.02	370	150	26	1.580	0.4550	40.0
2	83.29	10.98	3.89	0.92	350	150	28	1.350	0.6045	29.6
3	80.93	10.73	4.18	3.29	350	150	31	1.315	0.6340	34.3
4	89.87	4.33	4.23	1.29	370	150	30	1.357	0.6025	30.0
5	86.35	10.33	3.25	nil	400	150	30	1.375	0.5740	30.0
6	60.22	12.03	0.33	19.89	400	150	34	1.326	0.6440	24.1
7*	90.77	4.33	3.89	Tr.	350	150	20	1.738	0.3630	42.8
8	87.29	7.47	4.58	0.62	400	150	33	1.320	0.6340	30.0
9	77.52	11.25	9.98	0.75	400	150	31	1.273	0.6620	30.0

* Contains 0.53 per cent Ni.

† Priestly, *J. Inst. Metals*, 28:177-182 (1922).

‡ Load to produce cracking taken as UCS. Priestly gives deformation *vs.* compressive strength data.

Original size 1 in. diameter x 1 in.

TABLE 9.—*Friction Test.*

Bearing block:	bronze	Lining:	0.5 in. thick
Surface area:	4.8 sq. in.	Surface velocity:	565 ft./m.
Load:	4800 lbs.	Journal diam.:	6 in.
Unit load:	10,001 lbs. per sq. in.	Journal speed:	360 R.P.M.
Lubricant:	sperm oil		

(Prior to each test the machine was run several days in forward and reverse direction to secure perfectly smooth bearing surface.)

No.	Initial t °C.	t °C. after 4h	Increase	49° C.	60° C.	Max. t °C.
				— 10⁻⁴ Coefficient of Friction —		
1a	15.6	58.3	42.7	33	24	24
1b	"	62.2	46.6			
2a	"	62.2	46.6	62	44	39
2b	"	65.0	49.4			
3a	"	71.1	55.5	57	45	40
3b	"	70.6	55.0			
4a	"	75.0	59.4	31	28	23
4b	"	65.0	49.4			
5a	"	62.2	46.6	46	34	34
5b	"	69.4	54.0			
6a	"	62.2	46.6	41	30	26
6b	"	61.7	46.1			
7a	"	65.0	49.4	38	26	23
7b	"	62.2	46.6			
8a	"	59.4	43.8	35	31	29
8b	"	73.3	57.7			
9a	"	59.4	43.8	37	30	29
9b	"	61.7	46.1			

a = forward; b = reverse.

TABLE 10.—*Properties of Tin-Base White Metals.*[*]

Durability Test.

Lubricant: Sperm oil bath for 10 min.
Journal diameter: 6 in.
Journal speed: 360 R.P.M.
Load = 2400 lb. or 500 lbs. per sq. in.
Initial temperature = 15.6° C.

| No. | Temperature of Fusion, °C. | Time Element, Min. | —————Condition————— | |
			Bearing	Journal
1	148	88	a	c
2	150	62	a	c
3	147	41	b	d
4	134	72	b	d
5	160	38	b	c
6	139	72	a	c
7	166	52	a	c
8	159	78	a	c
9	163	75	a	c

a = slightly fused; b = considerably fused; c = no metal adhered;
d = metal adhered.

[*] Priestly, *J. Inst. Metals*, **28**:177-182 (1922). Priestly also gives time-temperature and time-friction data.

TABLE 11.—*Properties of the A.S.T.M. White Metals.*

Grade	Per Cent Composition*						Temperature °C			Compression, Lbs. per Sq. In.						Brinell Hardness No.	
	Sn	Sb	Pb	Cu	Max. Fe	Max. As	Melting Point, °C	Complete Liqua- tion, °C	Proper Pour- ing, Tem- per- ature °C	Ultimate		Yield Point‡		Elastic Limit§			
										20° C.	100° C.	20° C.	100° C.	20° C.	100° C.	20° C.	100° C.
1	91	4.5	0.35 max.	4.5	0.08	0.10	223	...	441	12,850	6,950	4,400	2,650	2,450	1,050	17	8
2	89	7.5	0.35 max.	3.5	0.08	0.10	241	354	424	14,900	8,700	6,100	3,000	3,330	1,100	24.5	12
3	83.3	8.33	0.35 max.	8.33	0.08	0.10	240	422	491	17,600	9,900	6,600	3,150	5,350	1,300	27	14.5
4	75	12	10	3	0.08	0.15	184	306	377	16,150	6,900	5,550	2,150	3,200	1,550	24.5	12
5	65	15	18	2	0.08	0.15	181	296	366	15,050	6,750	5,050	2,150	3,750	1,500	22.5	10
a**	61.5	10.5	25	3	0.08	0.15	:	...	...	...	...	...	...	...	...	...	...
b**	45	7.5	46	1.5	0.08	0.15	...	...	...	...	...	...	...	...	...	...	...
c**	30.5	8.5	60	1	0.08	0.15	...	...	...	...	...	...	...	...	...	...	...
6	20	15	63.5	1.5	0.08	0.15	181	277	346	14,550	8,050	3,800	2,050	3,550	1,800	21	10.5
7	10	15	75	0.5 max.	...	0.20	240	268	338	15,650	6,150	3,550	1,600	2,300	1,350	22.5	10.5
8	5	15	80	0.5 max.	...	0.20	237	272	341	15,650	6,150	3,400	1,750	2,650	1,200	20	9.5
9	5	10	85	0.5 max.	...	0.20	237	256	327	14,700	5,850	3,400	1,550	2,400	950	19	8.5
10	2	15	83	0.5 max.	...	0.20	242	264	332	15,450	5,750	3,350	1,850	2,250	1,200	17.5	9
11	...	15	85	0.5 max.	...	0.25	244	262	332	12,800	5,100	3,050	1,400	2,730	1,100	15	7
12	...	10	90	0.5 max.	...	0.25	245	259	329	12,900	5,100	2,800	1,250	2,250	950	14.5	6.5

*Zn and Al zero. Permitted variations (except in impurities) are 0.25 per cent for a specified content of not more than 2 per cent; 0.50 per cent from 2 to 5 per cent; 0.75 per cent from 5 to 10 per cent; 1.00 per cent over 10 per cent.

** See note to Table 12.

† Load causing 25 per cent reduction in length in a cylinder 1.5 in. long by 0.5 in. diameter.

‡ Load causing 0.125 per cent reduction in gage length.

§ Load corresponding to a rate of deformation 50 per cent greater than at initial load.

TABLE 12.—*Classification of White Metal Bearing Alloys.**

Class	Grade	Hard Constituents	Soft Constituents	Uses
A	1, 2	Sn-Cu compound.	Solid solution of Sb in Sn.	Almost all uses. Often replaceable by Class C.
	3	Sn-Cu compound and SnSb.		
B	4-6 and a-c	SnSb and Sn - Cu compound.	Eutectoid P and related structures.	Very thin linings of great fluidity and firm adherence.
C	7	SnSb.	Eutectoid O and related structures.	General service; alloy 7 especially suited to replace Class A alloys.
	8, 10	Sb or solution of Sn in Sb.		
	11	Sb crystals.	Pb-Sb eutectic.	
D	9	Eutectoid O.	Soft dendrites of Pb.	Unsuited to general service. For special use, as in lining railroad car bearings.
	12	Pb-Sb eutectic.		

* Table 11 shows the compositions and properties of the twelve alloys given in A.S.T.M. specification B23-26, and three alloys specified by the War Service Association of Manufacturers of Solder and Bearing Metals. The practice of applying a thin and easily renewed lining to the surface of a bronze bearing calls for alloys of great fluidity at pouring temperatures; these are indicated in the table. Table 12 summarizes the classification applied to this series by Wm. A. Cowan.

TABLE 13.—*Bureau of Standards Comparative Tests on Genuine Babbitt and Ulco Metal.***

Load, Lbs. per Sq. In.	R.P.M.	Total Revolutions	Final t °C.	Rise, t °C.	Friction, Lbs.	Loss, Grains
		Genuine Babbitt				
100	694	12,230	89	53	22	0.355
200	706	16,510	102	58	29	.324
300	682	15,150	125	100	38	.201
400	603	6,600	139	94	79	.833*
		Ulco Metal				
100	710	13,160	56	23	13	0.201
200	715	18,870	69	33	18	.324
300	719	18,830	80	42	27	.201
400	711	17,310	81	43	23	.339
500	723	17,660	79	43	25	.216
600	692	14,960	84	45	24	.324
700	648	24,520	62	38	24	.309
800	365	12,870	53	20	23	.154
900	408	22,300	59	22	24	.232
1000	405	23,200	66	36	22	.216†

** *Bur. Standards Circular* 101, p. 123.
* Bearing seized and smoking.
† Bearing still in good condition.

TABLE 14.—*Shrinkage and Volume Changes on Solidification (Miller).**

Per Cent Composition				Per Cent Expansion	Per Cent Shrinkage	Tensile Strength, Lbs. per Sq. In.
Cu, 90;	Sn, 8			0.05	1.500	33,500
	8.15;	Zn, 2.68		.059	1.535	25,000
	10.32	2.19		.041	1.497	30,800
	6.07	4.59		.045	1.605	25,600
	9.81	4.43		.030	1.457	29,200
Cu, 90;	Sn, 7;	Pb, 0.92		0.055	1.517	22,500
	6	2.14		.052	1.512	22,800
	5	2.90		.047	1.687	16,300
Cu, 92;	Sn, 5;	Ni, 2.64		0.035	1.710	30,500
	4	3.67		.037	1.730	34,600
Cu, 92;	Sn, 6;	P, 1.36		0.017	1.44	29,800

* *Metallurgie,* 9:63-71 (1912).

TABLE 15.—*Shrinkage and Volume Changes on Solidification (Wüst).**

Per Cent Composition					Per Cent Expansion	Per Cent Shrinkage
Cu, 87.10;	Sn, 2.68;	Zn, 8.05;	Pb, 2.28		0.025	1.76
81.06	17.50	1.53			.024	1.50
88.75	9.65	1.6			.058	1.47
86.65	9.84	2.00	1.44		.075	1.47
Cu, 94.70;	Sn, 5.08				0.085	1.66
89.65	10.23				.122	1.44
80.66	19.08				.01	1.52
Pb, 80.61;	Sb, 19.2				....	0.54
85.2	14.68				....	.56
Pb, 78.89;	Sb, 12.5;	Cu, 8.45			....	0.55
58.84	21.4	Sn, 19.80			....	.49
Sn, 85.42;	Sb, 9.45;	Cu, 5.10			....	0.51
90.20	8.00	1.85			....	.555
70.83	15.1	4.94	9.21		....	.425

* *Metallurgie,* 6:769-792 (1909).

TABLE 16.—*Thermal Conductivity of Some Industrial Alloys.**

Name	——— Per Cent Composition ———				t °C.	k
	Sn	Cu	Pb	Sb		
S.A.E. #10 †	92.5	3.6	0.2	3.7	50–100	0.092
#11	86.9	5.2	0.1	7.9	50–100	0.062
#12	0	7.1	63.9	28.8	50–100	0.076
#40	5.1	84.9	5.0	Zn 4.9	140–325	0.23
#62	10.6	86.6	0.04	Zn 2.8	155–340	0.142
#64	10.8	79.0	9.55	P 0.3	150–340	0.109
#66	5.6	85.3	8.3	Zn 0.7	140–320	0.177
Al Bronze	Cu 89.9; Al 9.1; Sn 0.5				130–350	0.174

* Williams and Bihlman, *Trans. Am. Inst. Mining Met. Eng.,* 69:1065-1069 (1923).

† Society of Automotive Engineers bearing alloy.

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